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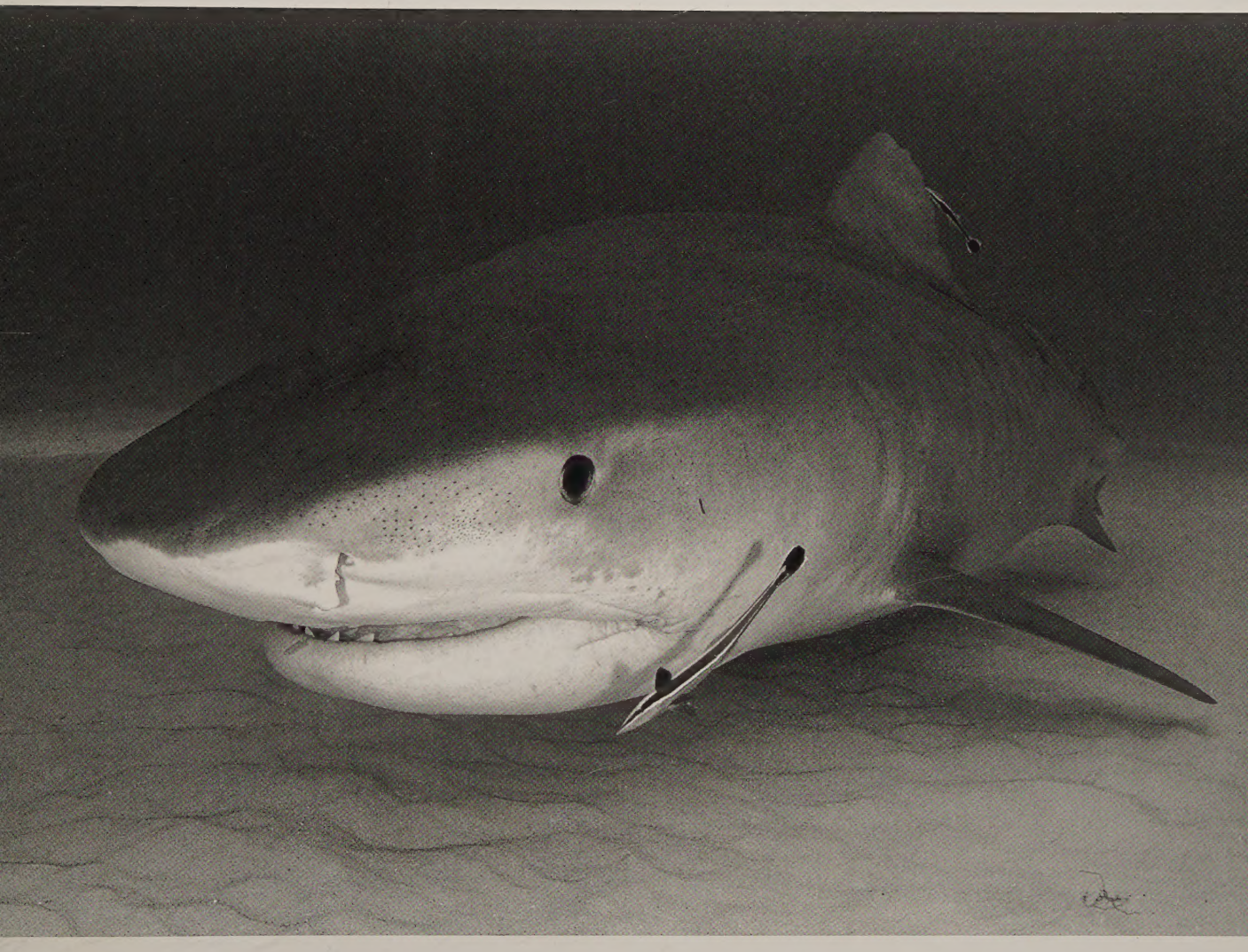

Tiger Shark,
Galeocerdo cuvier

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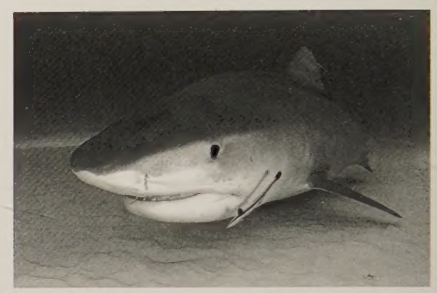

On the cover:
Tiger shark,
Galeocerdo cuvier
(Photo by Joe Romiero).

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Morphometric Conversions for 33 Shark Species from the Western North Atlantic Ocean

LISA J. NATANSON, CAMILLA T. McCANDLESS, MICHELLE S. PASSEROTTI, CAROLYN N. BELCHER, HEATHER BOWLBY, WILLIAM B. DRIGGERS III, BRYAN S. FRAZIER, JAMES GELSLEICHTER, SIMON J. B. GULAK, JILL M. HENDON, ERIC R. HOFFMAYER, and WARREN JOYCE

Introduction

It is well-established that accurate morphological data are important for a variety of fisheries science and management applications (Kohler et al., 1996; Mejuto and Garcia-Cortéz, 2005; Francis, 2006). For example, many recreational harvest regulations are length-based, while commercial landings data are often reported in weight which needs conversion to length for use in stock assessment models. Traditional stock assessment models use length-based parameters, such as size-at-age and size-at-maturity, as essential inputs (Maunder and Punt, 2013), while multiple data-limited assessment approaches estimate fishing mortality from changes in the length distribution (Chong et al., 2020). Further, assessing progress relative to management regulations often requires the ability to accurately convert among length measurements, such as precaudal, standard, fork, natural total, and stretched total lengths, due to inconsistencies in the types of standard measurements collected among various research programs (Francis, 2006). For example, straight-line fork length (FL_{SL}), which is measured as the straight-line distance from the tip of the snout to the fork of the tail, is the measurement type designated for shark regulations in the Atlantic Ocean by both the International Commission for the Conservation of Atlantic Tunas (ICCAT) and by NOAA's National Marine Fisheries Service Highly Migratory Species Division[1] (ICCAT, 2016). However, particularly for large fish, many researchers and fishermen use over-the-body (OTB; synonymous with curved measurements for this paper) measurements in which a measuring tape is laid along the surface of the body from the snout to various points on the tail. In wide-bodied species, such as the shortfin mako, *Isurus oxyrinchus*, and porbeagle, *Lamna nasus*, a fish measured OTB at the legal minimum size could be illegal using a straight-line measurement as they are generally shorter than OTB measurements.

Kohler et al. (1996) used data collected over a 29-year period by the NMFS Apex Predators Program, which included data from commercial, recreational, and scientific sampling to produce length-length and length-weight conversions for 13 shark species occurring off the U.S. Atlantic Coast from the Gulf of Maine to the Florida Keys. That study has been cited over 100 times in peer-reviewed literature and used extensively in stock assessments. Additionally, sport fishermen who enter many fishing tournaments in the U.S. Northeast are given Kohler et al.'s (1996) Table 2, length-weight key, so they can estimate the weight of their catch to verify that it meets tournament minimum weight. Herein, we compiled the data used in Kohler et al. (1996) (collected between 1961 and 1989), with additional data collected by the NMFS Apex Predators Program from 1990 to 2021, and data collected by eight additional programs (1993–2020) to expand upon previous results. This increased sample size

Lisa J. Natanson (Retired: mangrules@yahoo.ca), Camilla T. McCandless, and Michelle S. Passerotti are with the NOAA, NMFS, NEFSC Narragansett Laboratory, 28 Tarzwell Drive, Narragansett, RI 02882. Carolyn N. Belcher is with Georgia Department of Natural Resources, Coastal Resources Division, Brunswick, GA 31520. Heather Bowlby and Warren Joyce are with the Department of Fish and Oceans, Bedford Institute of Oceanography, Dartmouth, N.S., Canada. William B. Driggers III and Eric R. Hoffmayer are with the NOAA, NMFS, Southeast Fisheries Science Center, 3209 Frederic Street, Pascagoula, MS 39567. Bryan S. Frazier is with the South Carolina Department of Natural Resources, 217 Ft. Johnson Rd., Charleston, SC 29412. James Gelsleichter is with the Department of Biology, University of North Florida, 1 UNF Drive, Jacksonville, FL 32224. Simon Gulak is with Riverside Technology, Inc. (for NMFS) Fort Collins, CO, 80525. Jill Hendon is with the Center for Fisheries Research and Development, The University of Southern Mississippi, 703 East Beach Drive, Ocean Springs, MS 39564.

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[1]https://media.fisheries.noaa.gov/2020-12/HMS%20Recreational%20Compliance%20Guide_01_01_2020.pdf?nul=

ABSTRACT—This study generates and updates mathematical conversions among body length and weight measurements of sharks commonly encountered in the western North Atlantic Ocean. At the initiation of individual research programs, standardized measurements are determined to meet program objectives, yet these measurements often vary among programs and may differ within programs over time. Since length is of vital importance to understanding the basic biology of a species (e.g., growth, length at maturity) and to enforce management regulations based on size, it is necessary to have length-length and length-weight conversions to be able to standardize measurements for individual species. We compiled length and weight data on sharks from nine research programs operating in the western North Atlantic Ocean from Canada through the Gulf of Mexico to obtain length-length and length-weight conversions for 27 species and 3 genera consisting of 6 species. Length-length and length-weight conversions are presented for all species using over the body fork length as the independent variable. This study updates and expands previous conversions with new information.

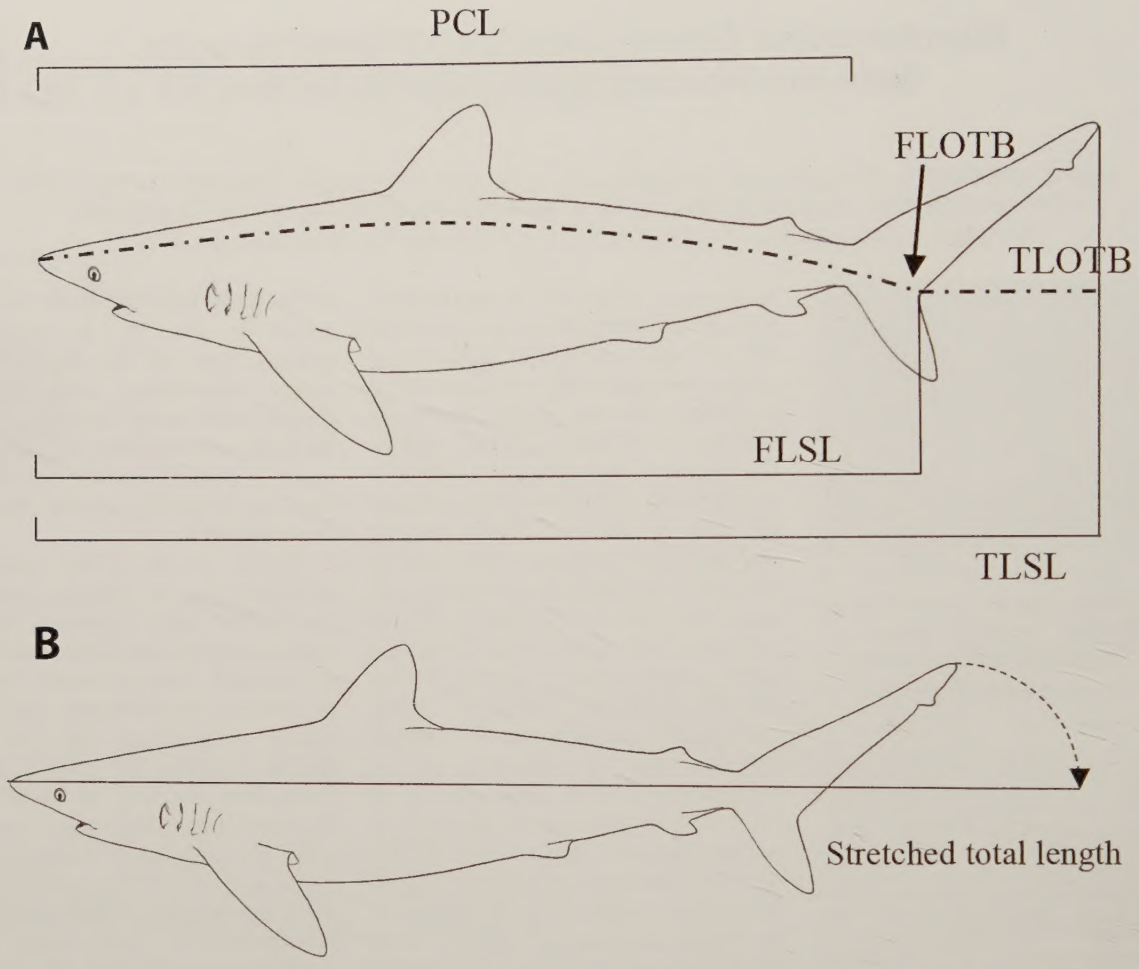

Figure 1.–Diagram showing the measurements that were used in this study. Straight-line measurements are denoted by the solid line while over-the-body (OTB; curved) measurements are denoted by a dash-dotted line. A) Straight-line and over-the-body total and fork length and straight-line precaudal length measurements. FLOTB=over-the-body fork length, FLSL = straight-line fork length, TLOTB=over-the-body total length, TLSL = straight-line total length, PCL = precaudal length. B) Stretched total length is taken with the upper lobe of the caudal fin stretched down to its fullest length in line with the center of the body.

allowed for a greater number of species to be included in these analyses along with a greater number of conversion formulas developed.

Methods

Data were compiled from nine programs conducting research in the western North Atlantic Ocean between Canada and the U.S. Gulf of Mexico (Table 1). Measurements of shark body length and weight data were obtained during research activities (e.g., fisheries-independent surveys) and from fishery-dependent sampling of commercial and recreational catch (e.g., sampling on commercial vessels and at sportfishing tournaments). Sharks were caught primarily on rod and reel at sportfishing tournaments and by gillnet and longline gear aboard research and commercial fishing vessels. Only lengths and weights measured by the authors or by cooperating biologists were used for this study.

Measurement types are defined as starting at the tip of the snout and ending at either the precaudal pit (PCL, where available), fork in the tail (FL, where available), or the tip of the caudal fin in its natural (TL) or stretched (TL_{STR}) position (Fig. 1). Measurements were taken either OTB or along a straight line (SL). The OTB measurements (e.g., FL_{OTB} and TL_{OTB}) used a flexible measuring tape over the dorsomedial curve of the body from point-to-point beneath the dorsal curve, while the SL measurements (e.g., FL_{SL} and TL_{SL}; also called caliper measurements) were taken from point-to-point along a straight line under or next to the body (Fig. 1A). Stretched TL was taken with the upper lobe of the caudal fin stretched to its fullest extension (Fig. 1B), while TL_{SL} and TL_{OTB} were taken at the perpendicular intercept of the tip of the upper lobe of the caudal fin in its "natural" position (Fig.

Table 1.–List of research programs contributing data for this study and the associated methods and measurement types. APP= Apex Predators Program, NMFS Narragansett Laboratory; DBC = Delaware Bay Cooperative Atlantic States Shark Pupping and Nursery (COASTSPAN) survey, NMFS Narragansett Laboratory; SEFSC MS = NMFS Southeast Fisheries Science Center (SEFSC) Pascagoula Laboratory; USM/GCRL = University of Southern Mississippi's Gulf Coast Research Laboratory; SEFSC PC = NMFS SEFSC Panama City Laboratory; CASRL = Canadian Atlantic Shark Research Laboratory, Department of Fisheries and Oceans, Dartmouth, Canada; UNF = University of North Florida; CRD = Coastal Resources Division of the Georgia Department of Natural Resources; SCDNR = South Carolina Department of Natural Resources Marine Resources Research Institute. FL = fork length; TL = total length; PCL = precaudal length; W = weight; OTB = over-the-body; SL = straight line; STR = stretched.

Program	Length Type							Measuring tape type	Board	Body position	End of PCL	Precision
	FL_{OTB}	FL_{SL}	TL_{OTB}	TL_{SL}	TL_{STR}	PCL	W					
APP	X	X	X	X	X		X	Metal	X[2]	Side		mm
DBC[1]	X		X		X	X	X	Flexible plastic	<90 cm	Side	Anterior margin	0.5 cm
SEFSC MS[1]	X	X	X	X	X	X	X	Flexible plastic	<200 cm FL	Side	Anterior margin	mm
USM/GCRL[1]		X		X	X	X	X	Flexible plastic	<150	Side	Center	mm
SEFSC PC[1]		X					X	Flexible plastic	X	Side		mm
CASRL	X	X					X	Flexible plastic		Side		0.5 cm
UNF[1]	X	X	X	X	X	X	X	Fabric	<120 cm	Belly	Deepest part	0.5 cm
CRD[1]		X		X	X		X	Fabric	< 4′	Side		mm
SCDNR[1]	X	X		X	X		X	Flexible plastic	<160 TL	Side		mm/cm[3]

[1]Used measuring board on smaller sharks changed to over-the-body on larger sharks.
[2]In the beginning few years of the APP small sharks were measured on a board, no longer used.
[3]Nearest mm for board and cm for OTB in the water.

1A). There were not enough verified data to determine if either PCL or TL_{STR} were OTB or SL, therefore, the measurements are combined. However, the majority of the programs either used SL for all of both measurements or for small sharks and then OTB on larger sharks; with the exception of the TL_{STR} for the common thresher shark, *Alopias vulpinus,* which was all OTB. Weight was measured in pounds (lb) or kilograms (kg) and standardized to kilograms for analyses. Species with ≥13 samples of any one combination of length–length or length–weight data with the sexes combined were chosen for analysis following Kohler et al. (1996).

The programs contributing to this publication used broadly similar measurement techniques with minor variations (Table 1). For example, in many cases, small sharks (size categories dependent on the program) were measured on a board using straight-line methods while larger sharks were measured OTB using a flexible measuring tape. All programs but one placed fish laterally for measurement, and all but three measured fish to the nearest millimeter. All length data were standardized to centimeter for analyses. The specific endpoint of the PCL measurement also varied among programs (Table 1). Weight (W) data were taken with varying resolutions depending on the type of scale used (e.g., 0.1 kg vs 0.5 kg).

After identifying and accounting for methodological differences to the extent possible, PCL, TL_{OTB}, TL_{STR}, and W were compiled according to species and plotted relative to FL_{OTB}; however, due to variations in reporting some FL_{SL} measurements may be included in the FL_{OTB} data for these relationships. Additionally, FL_{SL} and FL_{OTB} were compared for four species where these measurements were taken specifically to obtain this conversion (shortfin mako, porbeagle, common thresher shark, and blue shark, *Prionace glauca*). Due to the lack of a defined precaudal pit or forked tail in the nurse shark, *Ginglymostoma cirratum*, TL_{OTB} was used instead of FL_{OTB} and compared to W only. While it is recognized that the recently-described Carolina hammerhead, *Sphyrna gilberti*, differs genetically from the scalloped hammerhead, *S. lewini*, the two species are morphologically indistinguishable (Quattro et al., 2013). Therefore, while it is possible that length data from Carolina hammerheads was unknowingly included within the scalloped hammerhead data, the length-length relationships would be unaffected. Additionally, six species (*Mustelus norrisi, M. sinusmexicanis, Centrophorus granulosus, C. uyato, Squalus cubensis, S. mitsukurii*), collected by programs solely in the Gulf of Mexico, were combined into the genus groupings *Mustelus* spp., *Centrophorus* spp., and *Squalus* spp. due to close morphological similarities among congeners as well as taxonomic uncertainties (e.g., Verissimo et al., 2014; Giresi et al., 2015). All plots were rigorously examined for outliers which when identified were verified or corrected by each program. Any data that could not be verified were deleted (<1% of specimens).

Linear models in the form of $Y = a + b*FL_{OTB}$ were fitted for all potential length-length relationships for each species individually. Regressions for the length-length equations were tested for significant differences ($p<0.05$) in slopes and intercepts between the sexes using an ANCOVA and differences between the means were tested with an ANOVA. Fork length OTB–weight relationships were calculated separately for each sex and for sexes combined (with the exception of the nurse shark which

used TL_{OTB} rather than FL_{OTB}), and were fitted with power curves in the form of $W = aL^b$, where W = weight and L = FL_{OTB}. All analyses were conducted using R (R Core Development Team, 2020). Each species is presented alphabetically by common name in a two-page format with corresponding plots and data. For each species, a series of figures is presented depicting each length-length and length-weight relationship followed by tables with corresponding length ranges, regression coefficients, and sample sizes for each regression.

Results and Discussion

A total of 126,439 sharks representing 33 species were measured in this study. Data from 27 individual species and 3 genera consisting of six species, led to the 104 conversions calculated (Fig. 2–31; Suppl. Table 1). In 60 of the 74 length-length relationships no significant differences were found between the sexes ($p > 0.05$). For relationships with significant differences, one sex, usually females, achieved larger sizes than the other, therefore we truncated the data to include only those lengths where the sexes overlapped. These truncated datasets were then retested and no significant differences were detected in 12 of the 14 relationships. In one of these datasets, *Squalus* spp. FL_{OTB} to TL_{OTB}, the sample size of males was too small to use for an adequate comparison. The other dataset, blacktip sharks, *Carcharhinus limbatus*, showed significant differences between FL_{OTB} to PCL based on sex. Although this could not be explained, visual examination of the graph clearly shows no biological difference between the sexes, thus all sexes were combined for the length-length regressions (Fig. 2–31; Table 2–31).

Building upon the much-used morphometric conversions for 13 shark species in the western North Atlantic Ocean (Kohler et al., 1996), the incorporation of new data from the NMFS Apex Predators Program and other research programs allowed us to present more comprehensive and statistically robust conversion factors. Relative to sample size, the number of measurements from rarely-encountered species (n <200 in Kohler et al., 1996) increased by 24.0% to 98.2% and for more commonly-encountered species (n >200 in Kohler et al., 1996) from 47.9% to 91.4%. Relative to the number of conversions per species, we were able to add types of conversions (e.g., PCL and/or TL_{STR}) to 10 of the original 13 species. Additionally, we were able to report FL_{SL} to FL_{OTB} for some lamnids (i.e., porbeagle, shortfin mako), providing the first published conversions of this type for these species. For the 14 newly-included species and 3 genera, we were able to calculate >1 type of conversion for 94%, and > 2 for 82%.

Francis (2006) examined the variability of morphometric measurements to determine the best measurement methods for elasmobranchs and suggested that SL measurements are preferable to OTB measurements. However, SL measurements are often difficult or impossible to implement in the field, particularly when measuring large, active sharks. Therefore, several programs use SL measurement (measured on a board) for smaller animals and switch to OTB measurement for larger animals (Table 1). Francis (2006) found the SL and OTB performed equally as well but postulated that increased girth exhibited by a gravid female or a large feeding event, could inflate the OTB measurement. With the exception of one program, the OTB measurements used in the current study were reported as taken along the dorsomedial surface, not the lateral, thus, eliminating this concern. Despite the possibility that some of the FL_{OTB} dataset may contain some FL_{SL} measurements, we have good linear regressions with good fits and high r^2 values (Table 2–31). The difference in OTB and SL is smaller in the smaller sharks which are the only range where SL was possibly mixed into the OTB dataset.

In agreement with Kohler et al. (1996), we found FL to be measured more consistently than TL or PCL, mostly due to the lack of ambiguity in the fork as opposed to the TL (i.e., stretched or natural TL), or PCL which can be variable depending on the end point of the measurement (anterior, middle, or posterior margin of the precaudal pit). Additionally, as mentioned, in the field FL is the easiest and most consistent method for live fish, thus for consistency, using it for all size ranges is suggested when possible. Further, due to the subjectivity concerning the "natural" position of the flexible upper lobe of the caudal fin for many shark species (e.g., carcharhinids), we agree with Francis (2006) that natural TL is the least preferable measure, but it should be taken in cases where robust conversions among this and other measures are not available for a given species. While Francis (2006) suggested at least two measurement methods be taken for each fish to facilitate conversions, we instead suggest that a minimum of three length measurements or two lengths and a weight measurement be taken, to prevent single errors in data transcription from rendering an entire sample useless.

The need for accurate and precise morphometric conversions cannot be overstated. Conversions are the building block of biological analysis of a species. Depending on the intended use of the data, the first step in many studies is to ensure all the measurements are in the same format. Using inaccurate lengths, for example, in an age analysis, will lead to inaccurate age estimates amplifying errors in downstream analyses. These compounded errors affect the accuracy of cohort tracking through stock assessments, which can become particularly problematic for the oldest, least abundant age classes. These updated and expanded length and weight conversions provide a more definitive resource to aid shark stock assessment and fisheries management in the Atlantic Ocean.

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Atlantic Sharpnose Shark, *Rhizoprionodon terraenovae*

Table 2A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for Atlantic sharpnose sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	25.0–99.0	29.0–116.5	3.35	1.15	0.979	18,005
Female	26.0–99.0	29.0–116.5				9,574
Male	25.0–97.4	29.5–113.0				8,365

Table 2B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for Atlantic sharpnose sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	20.0–105.5	24.9–129.4	2.09	1.18	0.996	36,736
Female	21.0–105.5	26.4–129.4				11,597
Male	20.0–101.5	24.9–123.3				24,859

Table 2C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for Atlantic sharpnose sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	21.0–99.0	19.0–92.1	-0.979	0.932	0.997	11,758
Female	21.0–99.0	19.0–92.1				4,104
Male	23.0–95.8	20.0–88.2				7,586

Table 2D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for Atlantic sharpnose sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	r^2	*n*
Combined	26.5–99.0	0.1–7.2	5.92E-06	2.06	0.350	25,699
Female	26.5–99.0	0.1–7.2	6.14E-06	3.05	0.365	12,737
Male	28.1–97.4	0.1–6.8	9.27E-06	2.95	0.316	12,857

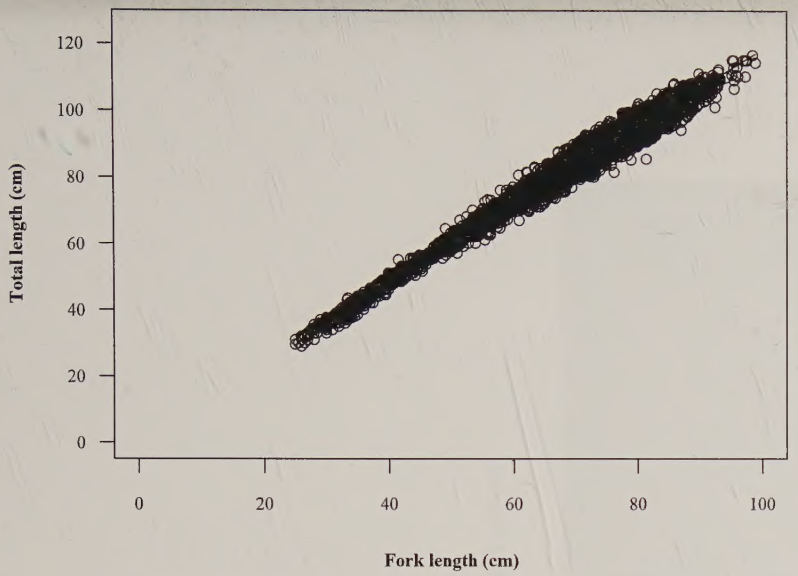


Figure 2A.–Relationship between over-the-body fork length and total length for Atlantic sharpnose sharks from the western North Atlantic Ocean (sexes combined).

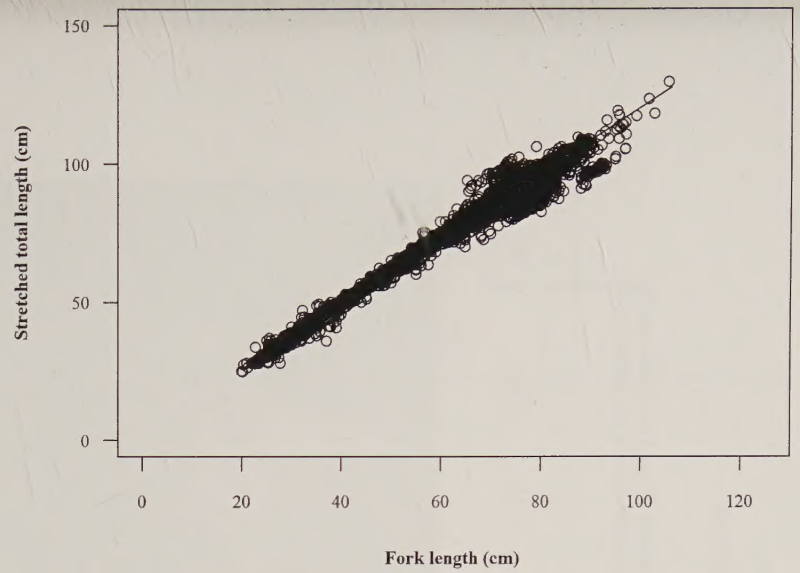


Figure 2B.–Relationship between over-the-body fork length and stretched total length for Atlantic sharpnose sharks from the western North Atlantic Ocean (sexes combined).

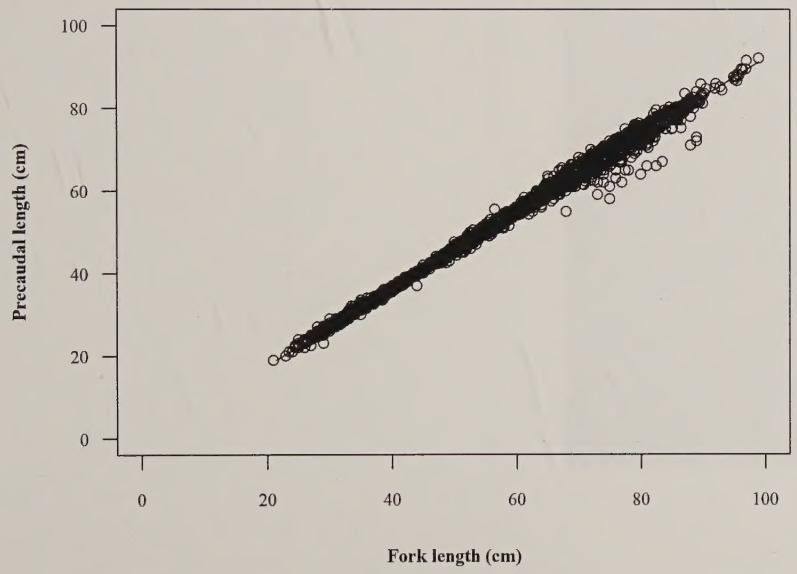


Figure 2C.–Relationship between over-the-body fork length and precaudal length for Atlantic sharpnose sharks from the western North Atlantic Ocean (sexes combined).

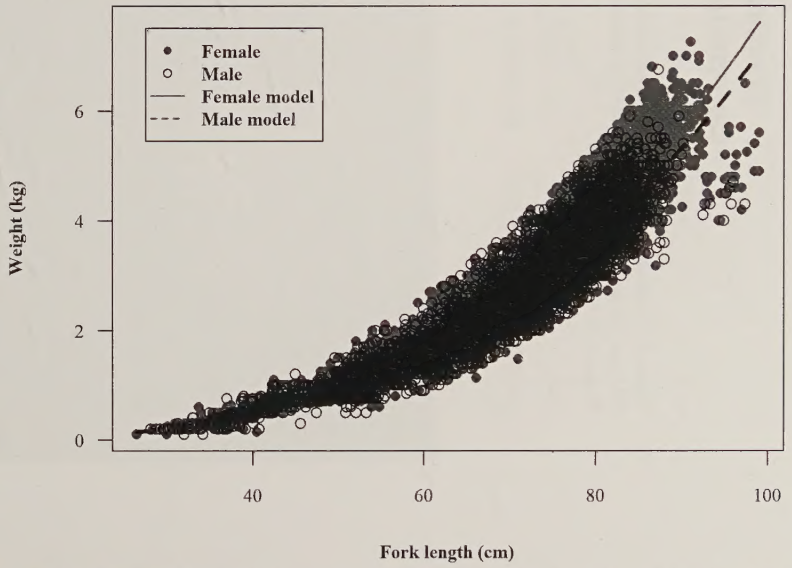


Figure 2D.–Relationship between over-the-body fork length and total weight for Atlantic sharpnose sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Basking Shark, *Cetorhinus maximus*

Table 3.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for basking sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	320.0–780.9	362.0–855.3	-3.48	1.13	0.987	12

Basking shark. Photo: Greg Skomal.

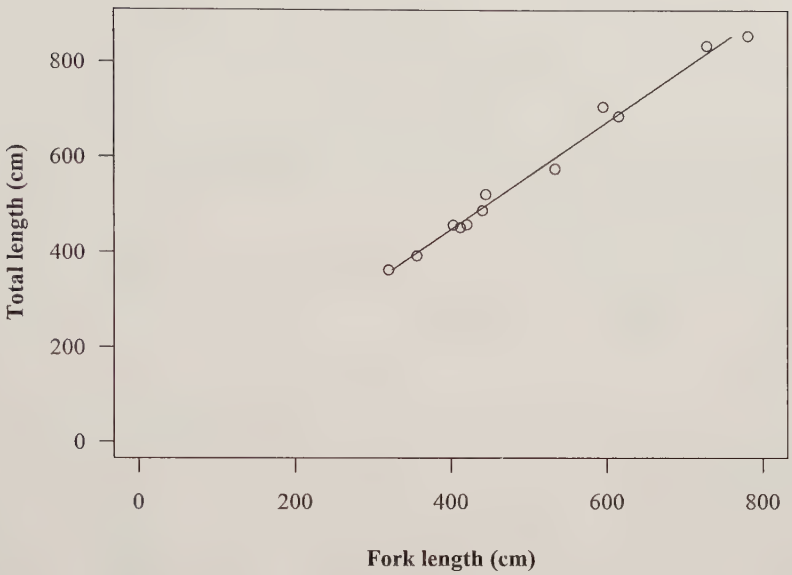


Figure 3.–Relationship between over-the-body fork length and total length for basking sharks from the western North Atlantic Ocean (sexes combined).

Bigeye Thresher, *Alopias superciliosus*

Table 4A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for bigeye thresher sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	100.0–228.0	155.0–371.0	5.55	1.60	0.887	58
Female	138.0–228.0	233.0–371.0				28
Male	100.0–221.0	155.0–363.0				30

Table 4B.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for bigeye thresher sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	100.0–228.0	11.3–170.1	8.03E-06	3.10	9.74	57
Female	123.0–228.0	23.1–170.1	1.49E-05	3.00	9.43	23
Male	100.0–221.0	11.3–149.7	6.09E-06	3.15	8.60	34

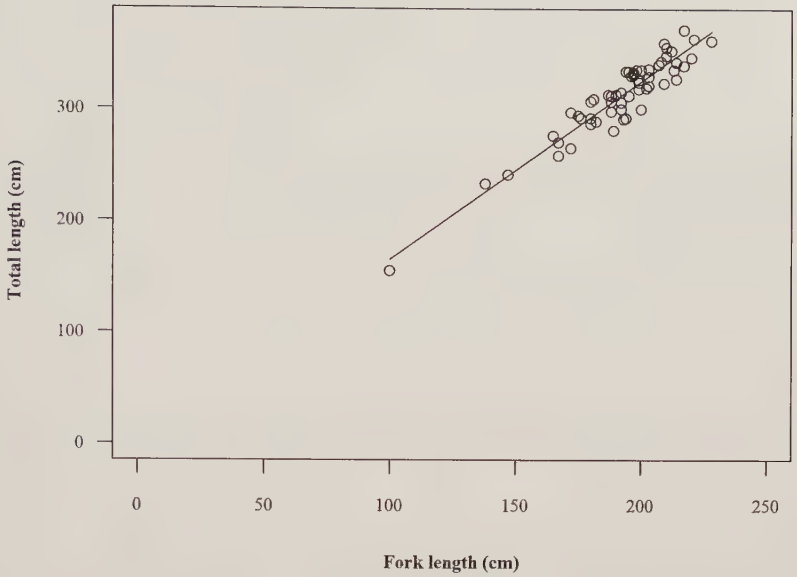


Figure 4A.–Relationship between over-the-body fork length and total length for bigeye thresher sharks from the western North Atlantic Ocean (sexes combined).

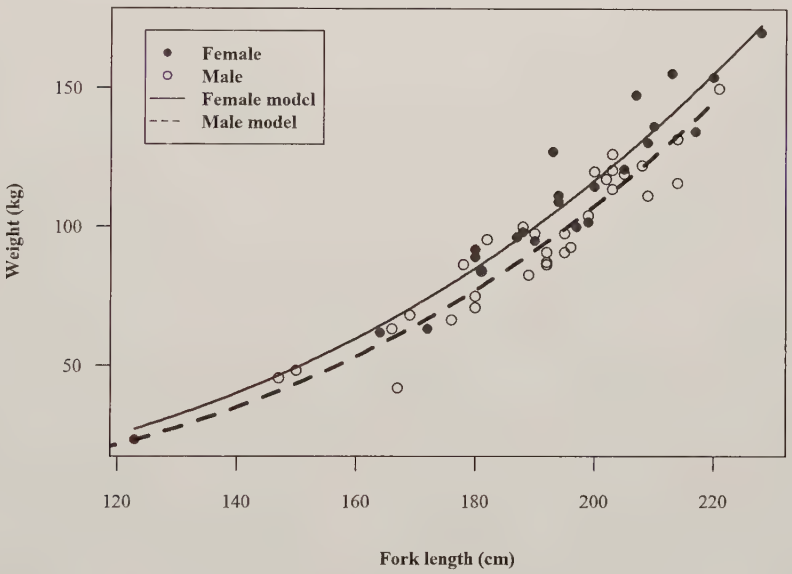


Figure 4B.–Relationship between over-the-body fork length and total weight for bigeye thresher sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Bignose Shark, *Carcharhinus altimus*

Table 5A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for bignose sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b^{*}FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	67.8–192.0	81.5–228.0	0.877	1.17	0.994	21
Female	73.5–192.0	87.5–228.0				13
Male	67.8–140.0	81.5–168.0				8

Table 5B.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for bignose sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	67.8–210.0	3.7–142.9	1.43E-06	3.40	8.46	48
Female	73.5–210.0	3.9–142.9	7.58E-07	3.53	9.60	30
Male	67.8–205.0	3.7–98.9	4.62E-06	3.16	5.22	18

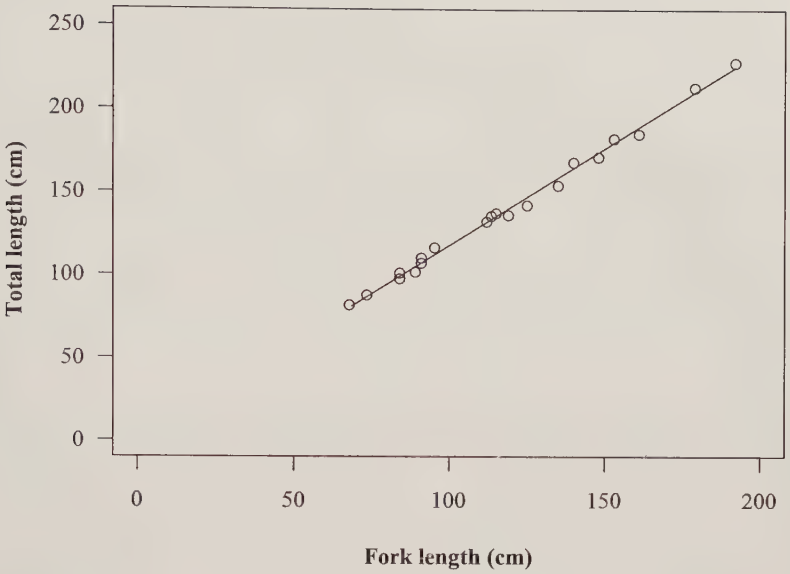


Figure 5A.–Relationship between over-the-body fork length and total length for bignose sharks from the western North Atlantic Ocean (sexes combined).

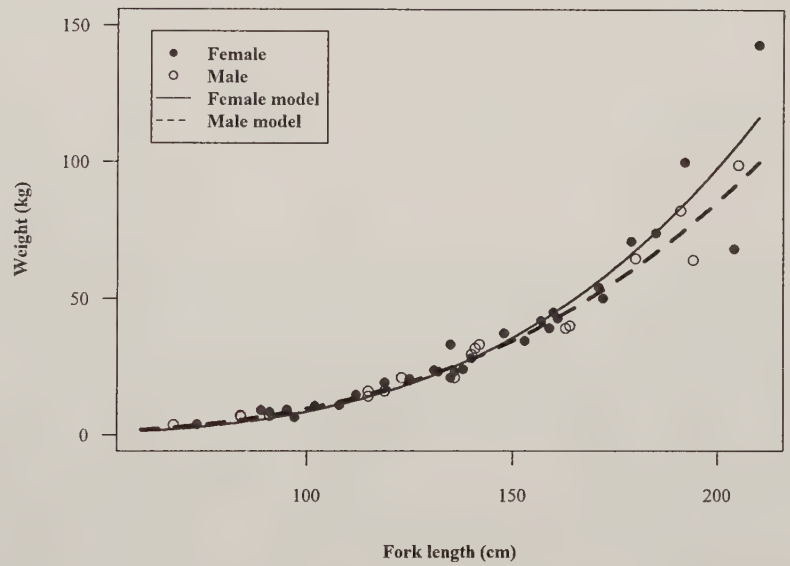


Figure 5B.–Relationship between over-the-body fork length and total weight for bignose sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Blacknose Shark, *Carcharhinus acronotus*

Table 6A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for blacknose sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	40.0–110.0	47.5–130.0	7.73	1.10	0.940	2,386
Female	40.0–110.0	47.5–130.0				1,029
Male	43.0–107.0	51.5–126.8				1,337

Table 6B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for blacknose sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	33.3–128.0	41.7–156.0	5.73	1.17	0.970	4,942
Female	33.3–128.0	41.7–156.0				2,528
Male	37.3–121.1	46.5–152.3				2,388

Table 6C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for blacknose sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	44.5–128.0	39.8–104.0	0.128	0.909	0.982	1,052
Female	44.5–128.0	39.8–104.0				467
Male	45.7–113.0	41.3–99.0				579

Table 6D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for blacknose sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	33.3–118.0	0.35–24.0	2.52E-06	3.32	1.25	3,997
Female	33.3–118.0	0.35–24.0	2.10E-06	3.37	1.42	1,872
Male	37.3–113.0	0.42–20.0	3.39E-06	3.25	1.02	2,106

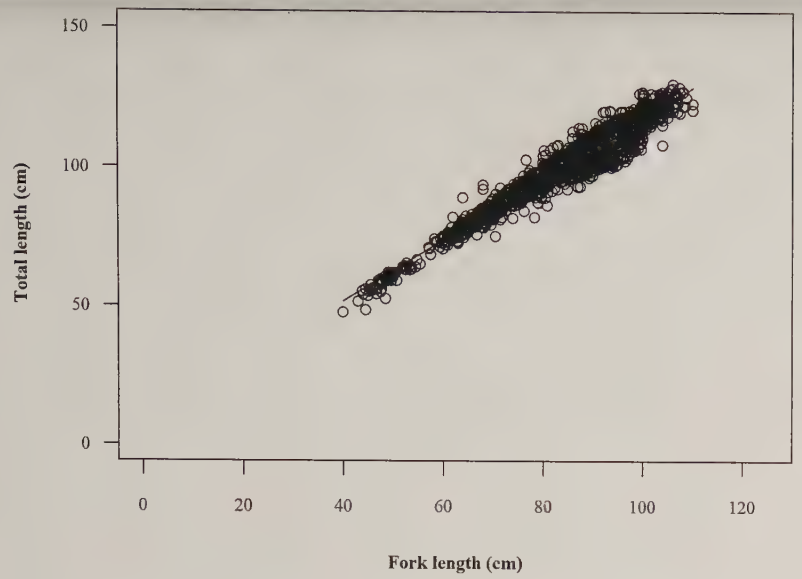


Figure 6A.–Relationship between over-the-body fork length and total length for blacknose sharks from the western North Atlantic Ocean (sexes combined).

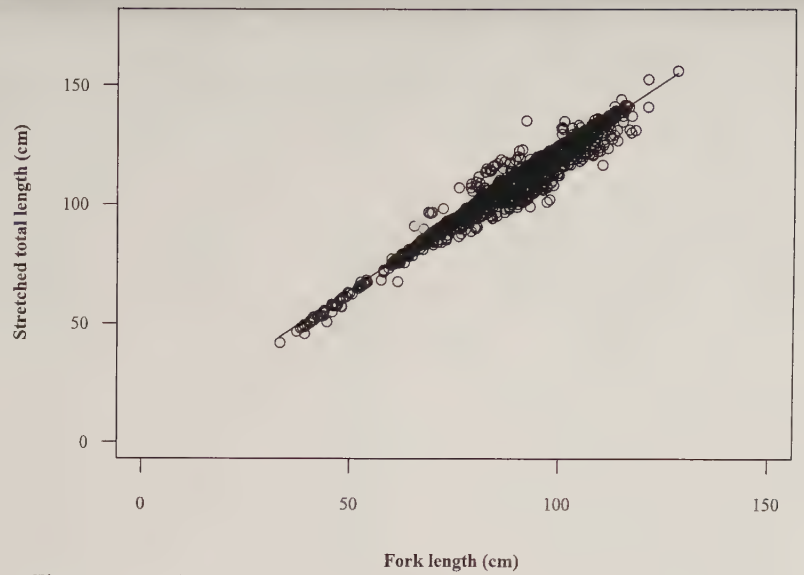


Figure 6B.–Relationship between over-the-body fork length and stretched total length for blacknose sharks from the western North Atlantic Ocean (sexes combined).

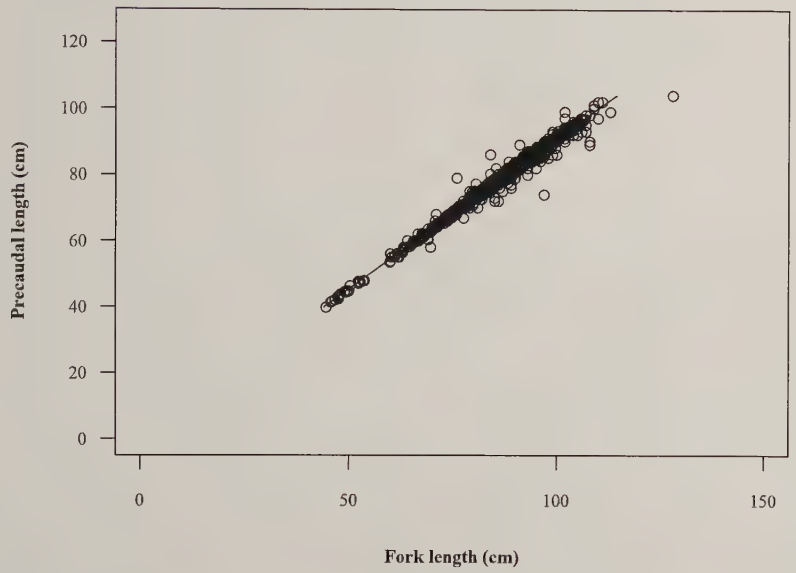


Figure 6C.–Relationship between over-the-body fork length and precaudal length for blacknose sharks from the western North Atlantic Ocean (sexes combined).

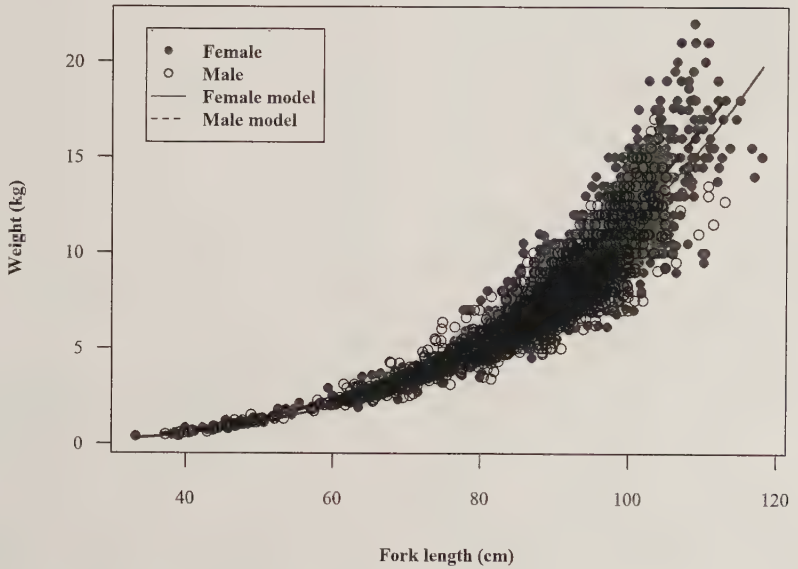


Figure 6D.–Relationship between over-the-body fork length and total weight for blacknose sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Blacktip Shark, *Carcharhinus limbatus*

Table 7A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for blacktip sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	42.0–158.0	51.0–188.0	2.83	1.17	0.976	1,541
Female	42.0–158.0	51.0–188.0				777
Male	45.0–150.0	53.0–182.0				737

Table 7B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for blacktip sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	36.5–166.0	44.3–197.0	1.51	1.23	0.996	5,880
Female	36.5–166.0	44.3–197.0				3,296
Male	37.0–149.5	48.0–189.0				2,504

Table 7C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for blacktip sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	36.5–166.0	30.0–146.0	-0.186	0.904	0.998	2,276
Female	36.5–166.0	30.0–146.0				1,245
Male	38.0–143.0	34.2–128.0				996

Table 7D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for blacktip sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	38.0–175.0	0.2–66.0	1.17E-05	3.02	2.42	2,635
Female	41.0–158.0	0.2–65.0	7.12E-06	3.13	2.57	1,328
Male	38.0–151.7	0.2–44.0	2.77E-05	2.82	1.90	1,275

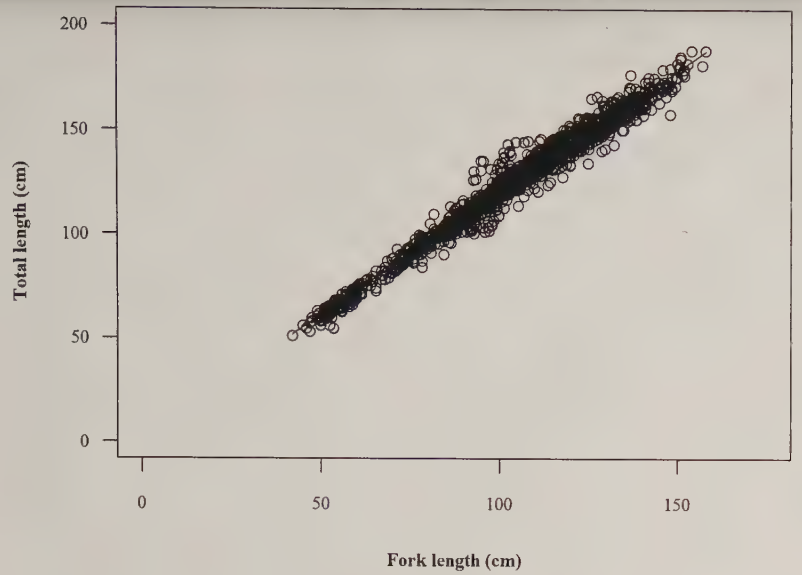


Figure 7A.–Relationship between over-the-body fork length and total length for blacktip sharks from the western North Atlantic Ocean (sexes combined).

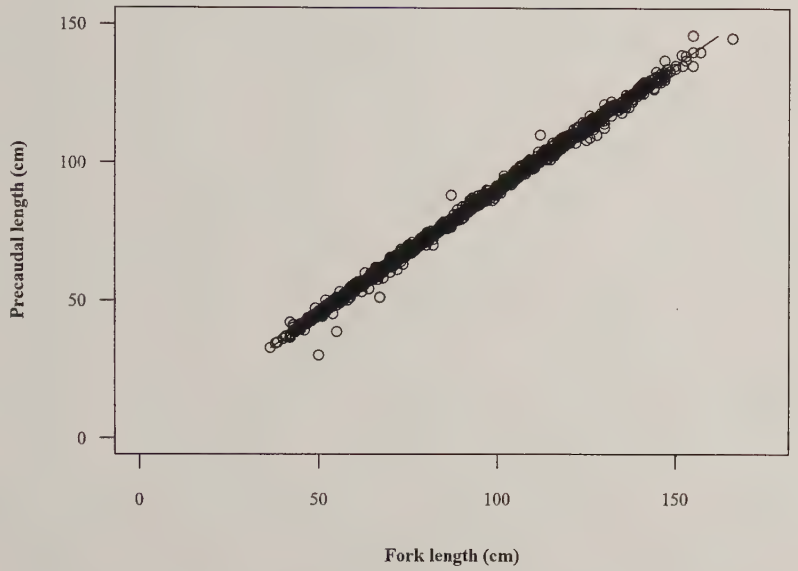


Figure 7C.–Relationship between over-the-body fork length and precaudal length for blacktip sharks from the western North Atlantic Ocean (sexes combined).

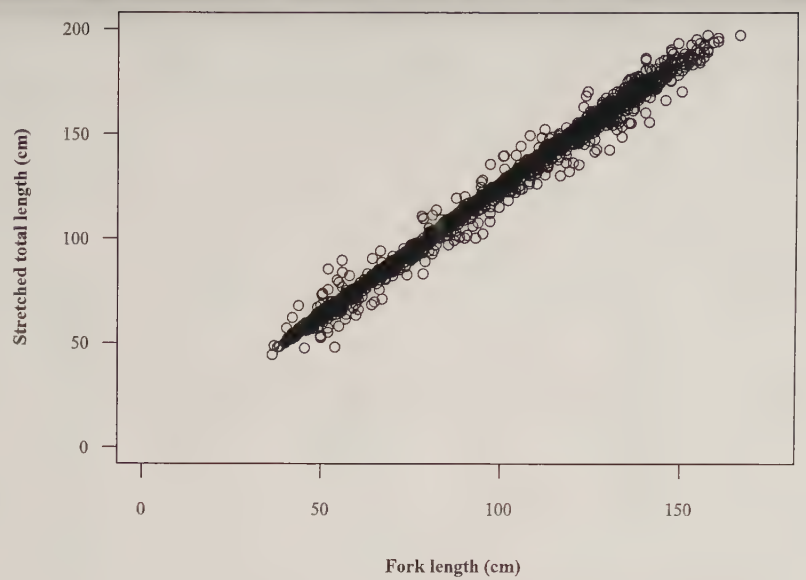


Figure 7B.–Relationship between over-the-body fork length and stretched total length for blacktip sharks from the western North Atlantic Ocean (sexes combined).

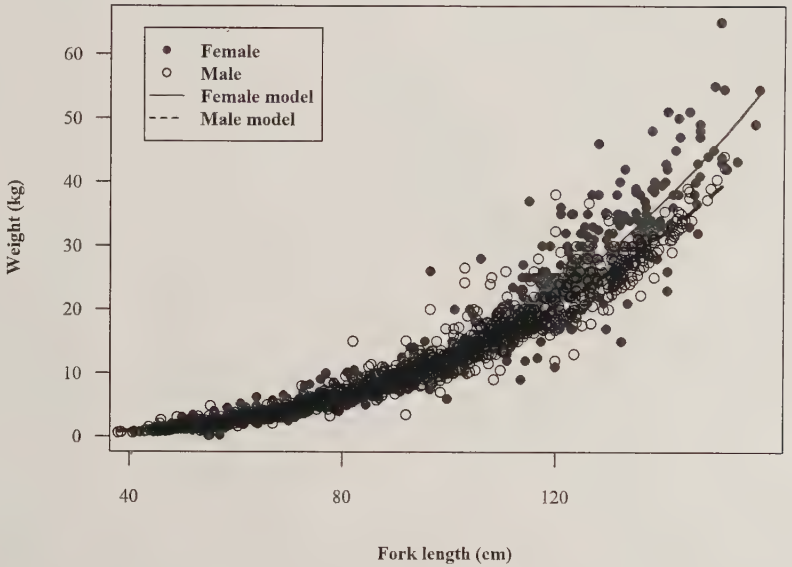


Figure 7D.–Relationship between over-the-body fork length and total weight for blacktip sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Blue Shark, *Prionace glauca*

Table 8A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for blue sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	52.0–299.2	64.0–373.0	0.459	1.19	0.989	946
Female	52.0–266.0	64.0–316.0				178
Male	54.0–299.2	65.0–373.0				762

Table 8B.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for blue sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	52.0–300.0	0.45–213.4	3.76E-06	3.10	7.32	7,879
Female	52.0–273.0	0.45–148.3	4.26E-06	3.08	4.16	1,566
Male	54.0–300.0	0.91–213.4	2.87E-06	3.15	7.88	6,248

Table 8C.–Relationship between over-the-body fork length (FL_{OTB}) and straight-line fork length (FL_{SL}) for blue sharks from the western North Atlantic Ocean in the form of $FL_{OTB} = a + b*FL_{SL}$.

Sex	CFL range	SFL range	a	b	r^2	*n*
Combined	76.5–294.6	73.0–291.2	-0.9004	0.9803	0.9928	790
Female	76.5–207.0	73.0–200.0				486
Male	140.0–294.6	139.0–291.2				304

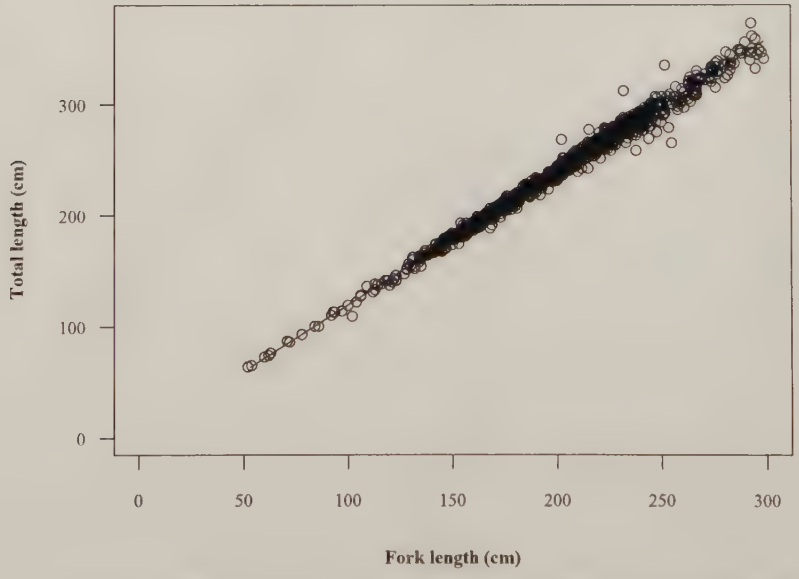


Figure 8A.–Relationship between over-the-body fork length and total length for blue sharks from the western North Atlantic Ocean (sexes combined).

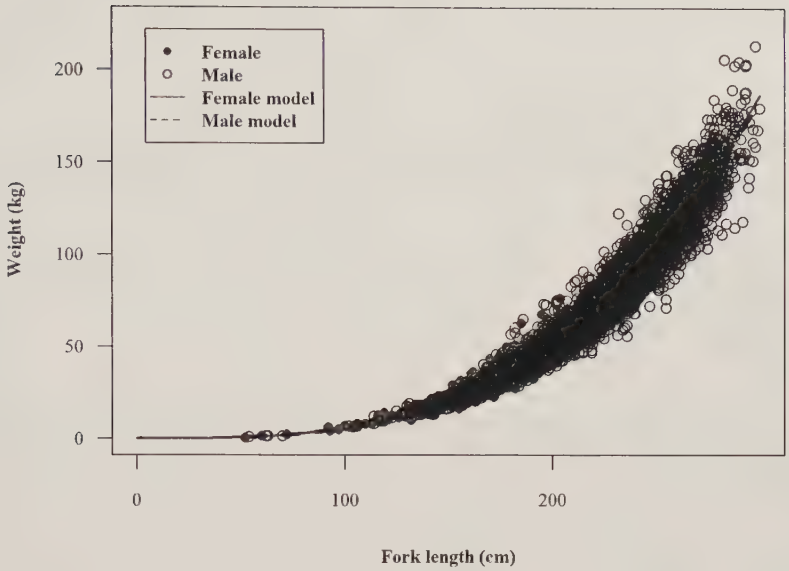


Figure 8B.–Relationship between over-the-body fork length and total weight for blue sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

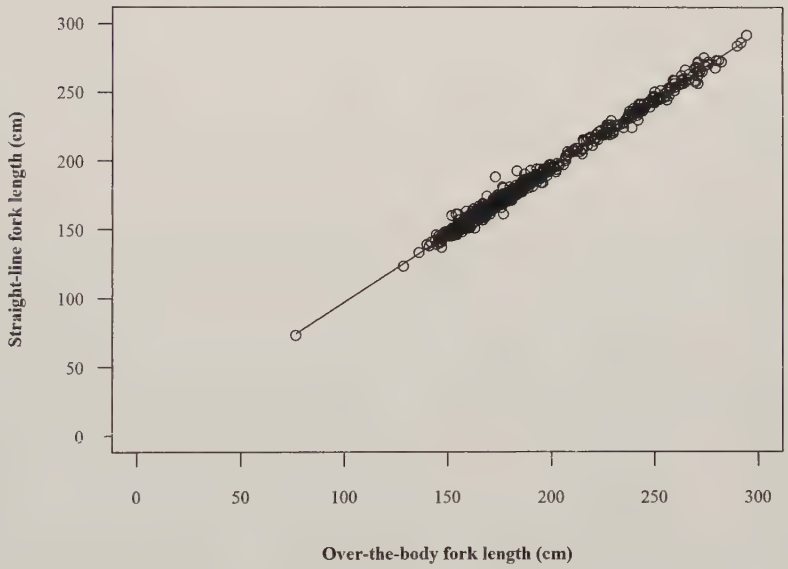


Figure 8C.–Relationship between over-the-body fork length and straight-line fork length for blue sharks from the western North Atlantic Ocean (sexes combined).

Bonnethead, *Sphyrna tiburo*

Table 9A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for bonnetheads from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	36.5–100.0	44.0–124.0	4.73	1.14	0.980	172
Female	36.5–100.0	44.0–124.0				126
Male	37.0–84.0	45.0–101.0				45

Table 9B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for bonnetheads from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	22.0–107.4	27.9–132.0	3.70	1.20	0.992	7,627
Female	23.0–107.4	29.3–132.0				5,635
Male	22.0–86.1	27.9–107.0				1,922

Table 9C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for bonnetheads from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	27.0–105.5	24.0–96.5	-0.583	0.926	0.997	765
Female	31.5–105.5	28.5–96.5				387
Male	27.0–86.0	24.0–80.0				372

Table 9D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for bonnetheads from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	22.0–105.5	0.05–12.0	1.31E-06	3.43	0.623	2,467
Female	23.0–105.5	0.09–12.0	2.70E-06	3.27	0.777	1,384
Male	22.0–85.5	0.05–7.0	6.53E-06	3.03	0.282	1,035

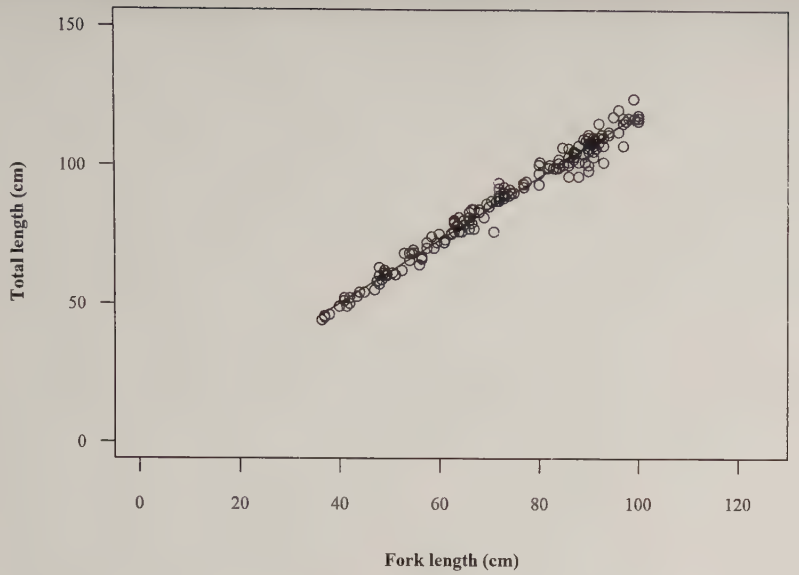


Figure 9A.–Relationship between over-the-body fork length and total length for bonnetheads from the western North Atlantic Ocean (sexes combined).

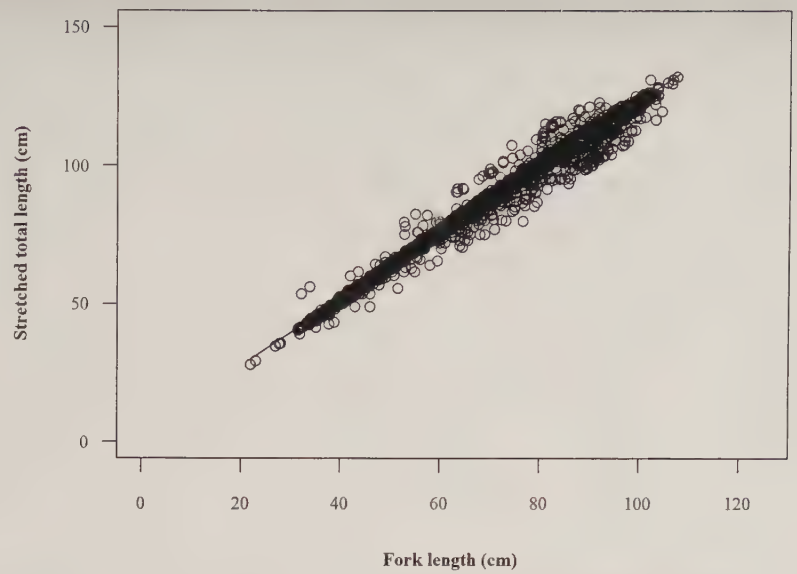


Figure 9B.–Relationship between over-the-body fork length and stretched total length for bonnetheads from the western North Atlantic Ocean (sexes combined).

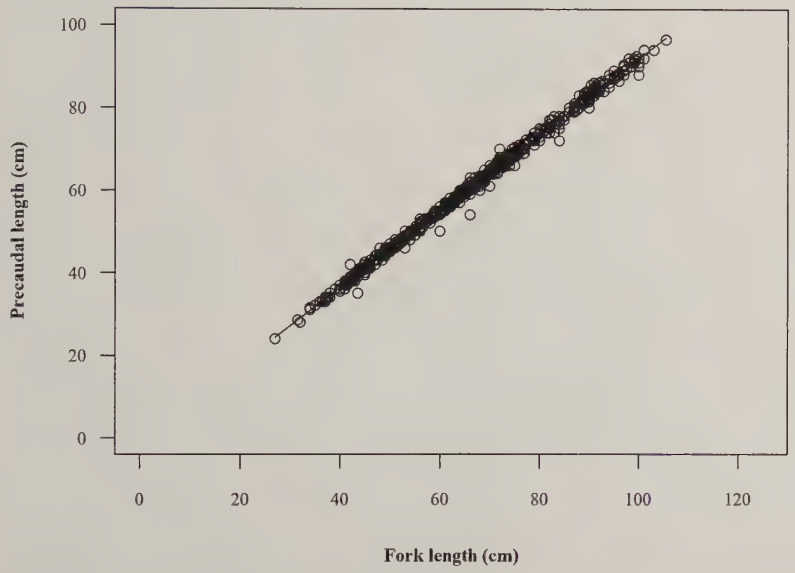


Figure 9C.–Relationship between over-the-body fork length and precaudal length for bonnetheads from the western North Atlantic Ocean (sexes combined).

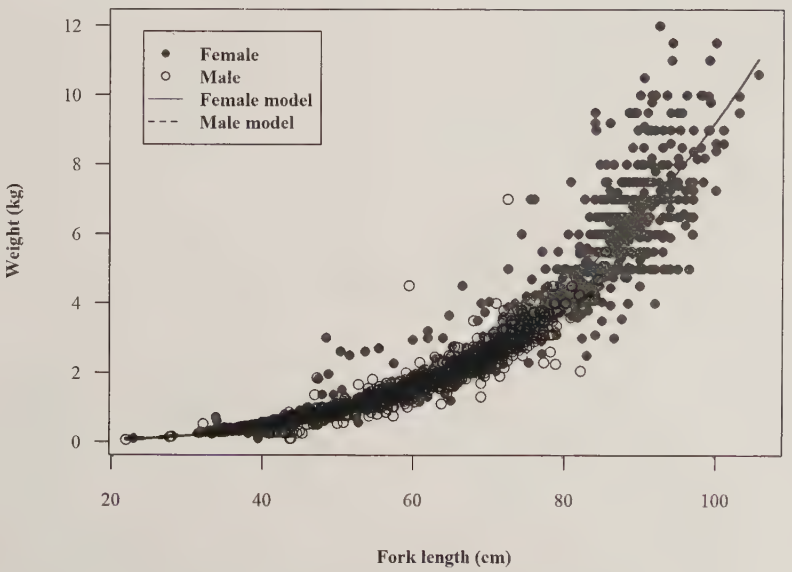


Figure 9D.–Relationship between over-the-body fork length and total weight for bonnetheads from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Bull Shark, *Carcharhinus leucas*

Table 10A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for bull sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	59.0–225.0	70.0–260.0	2.93	1.16	0.990	115
Female	61.0–213.0	73.0–260.0				41
Male	59.0–225.0	70.0–250.0				74

Table 10B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for bull sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	36.4–310.0	43.5–355.0	2.80	1.21	0.992	386
Female	54.0–310.0	66.5–355.0				161
Male	57.0–208.1	71.5–253.1				216

Table 10C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for bull sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	36.4–235.0	34.0–212.2	-0.325	0.899	0.999	289
Female	54.0–235.0	48.0–212.2				119
Male	57.0–208.1	50.0–189.0				164

Table 10D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for bull sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	36.4–225.0	1.0–170.5	1.36E-05	3.01	9.86	136
Female	54.0–213.0	2.0–170.5	2.16E-06	3.37	9.80	43
Male	57.0–225.0	2.7–151.0	3.05E-05	2.85	9.64	92

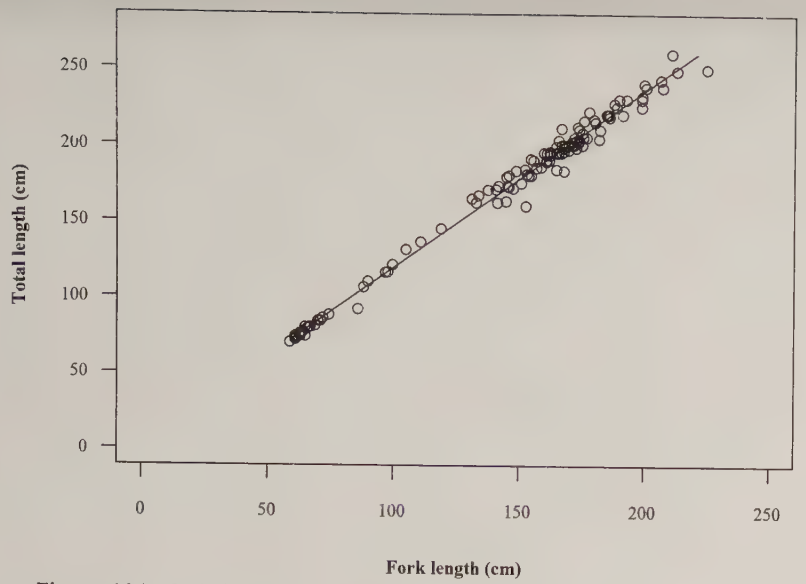


Figure 10A.–Relationship between over-the-body fork length and total length for bull sharks from the western North Atlantic Ocean (sexes combined).

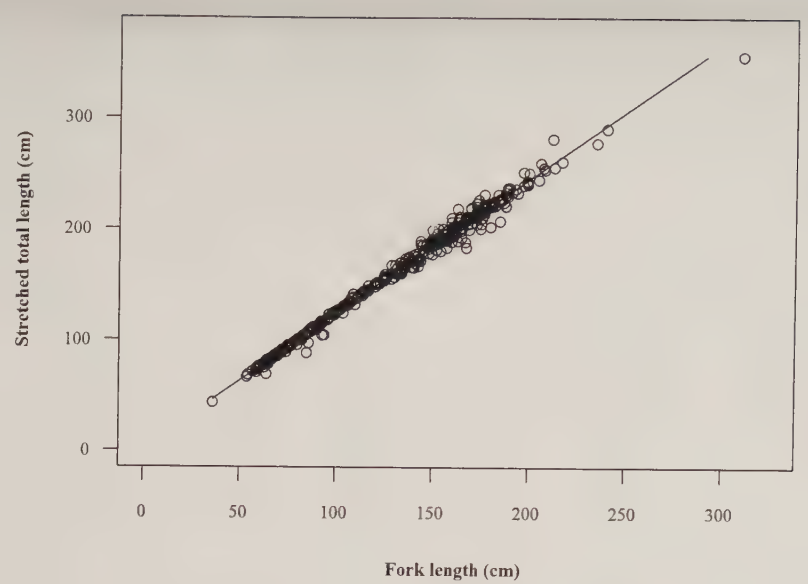


Figure 10B.–Relationship between over-the-body fork length and stretched total length for bull sharks from the western North Atlantic Ocean (sexes combined).

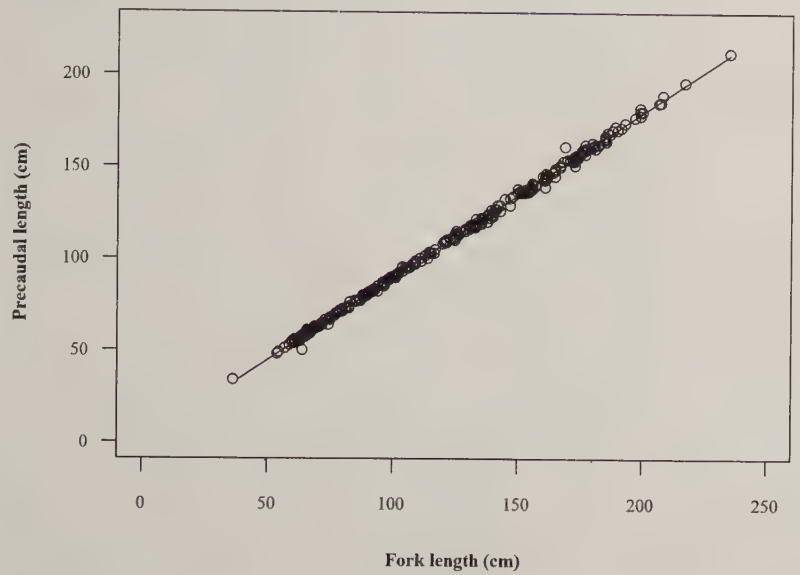


Figure 10C.–Relationship between over-the-body fork length and precaudal length for bull sharks from the western North Atlantic Ocean (sexes combined).

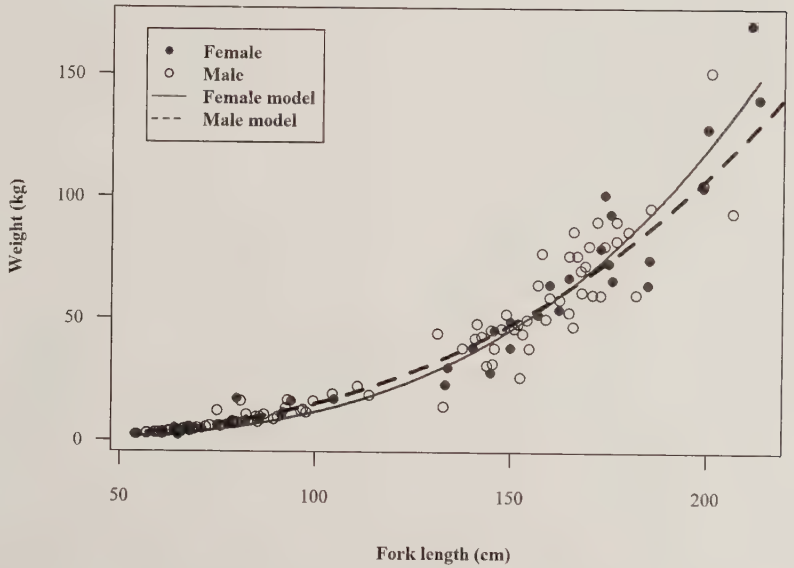


Figure 10D.–Relationship between over-the-body fork length and total weight for bull sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Centrophorus spp.

Table 11A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for *Centrophorus* spp., from the Gulf of Mexico in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	47.4–94.2	52.9–106.5	0.122	1.10	0.977	123
Female	47.4–94.2	52.9–106.5				114
Male	55.2–76.7	61.8–87.3				8

Table 11B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for *Centrophorus* spp., from the Gulf of Mexico in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	52.0–95.2	59.9–108.4	0.855	1.13	0.997	76
Female	52.0–95.2	59.9–108.4				55
Male	55.2–79.5	63.1–90.6				21

Table 11C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for *Centrophorus* spp., from the Gulf of Mexico in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	66.0–95.2	58.0–85.4	-2.05	0.931	0.961	45
Female	77.6–95.2	71.2–85.4				31
Male	66.0–79.5	58.0–70.9				14

Table 11D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for *Centrophorus* spp., from the Gulf of Mexico in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	47.4–95.2	0.6–8.5	1.03E-05	2.97	0.567	180
Female	47.4–95.2	0.6–8.5	4.04E-05	2.67	0.587	156
Male	55.2–79.5	1.4–4.2	3.36E-05	2.68	0.234	22

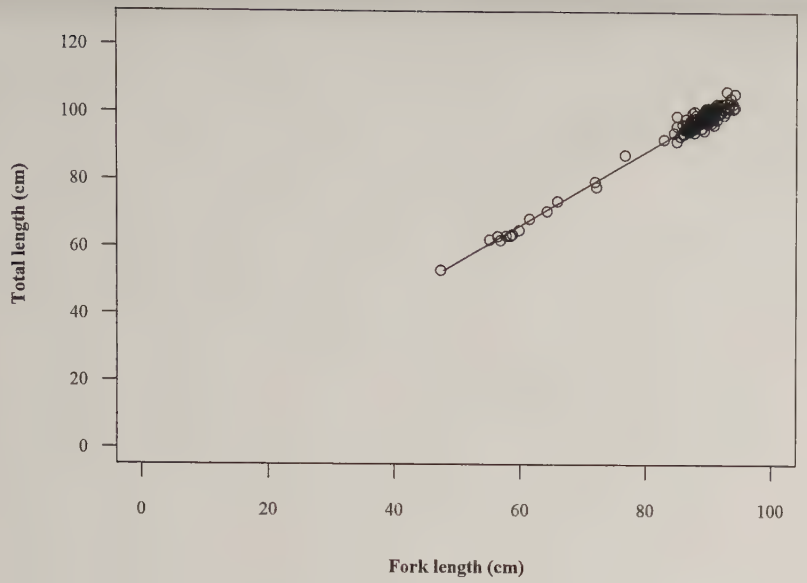


Figure 11A.–Relationship between over-the-body fork length and total length for *Centrophorus* spp., from the western North Atlantic Ocean (sexes combined).

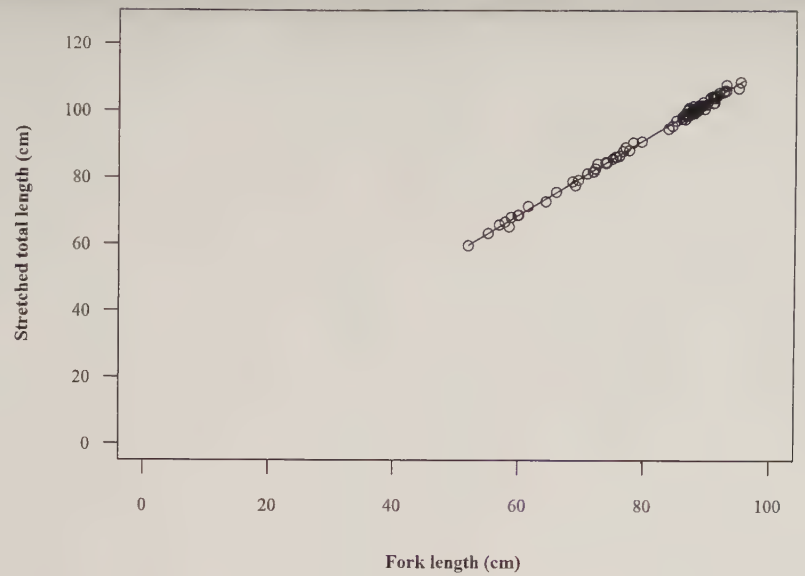


Figure 11B.–Relationship between over-the-body fork length and stretched total length for *Centrophorus* spp., from the western North Atlantic Ocean (sexes combined).

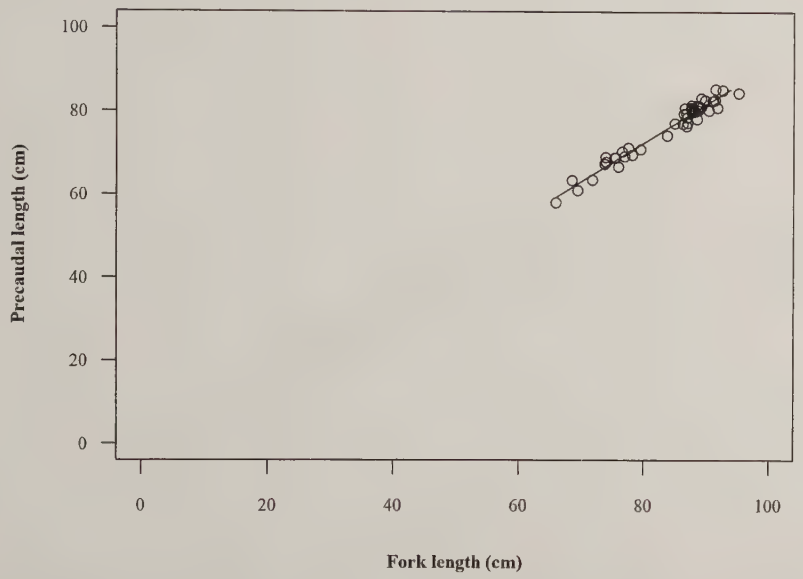


Figure 11C.–Relationship between over-the-body fork length and precaudal length for *Centrophorus* spp., from the western North Atlantic Ocean (sexes combined).

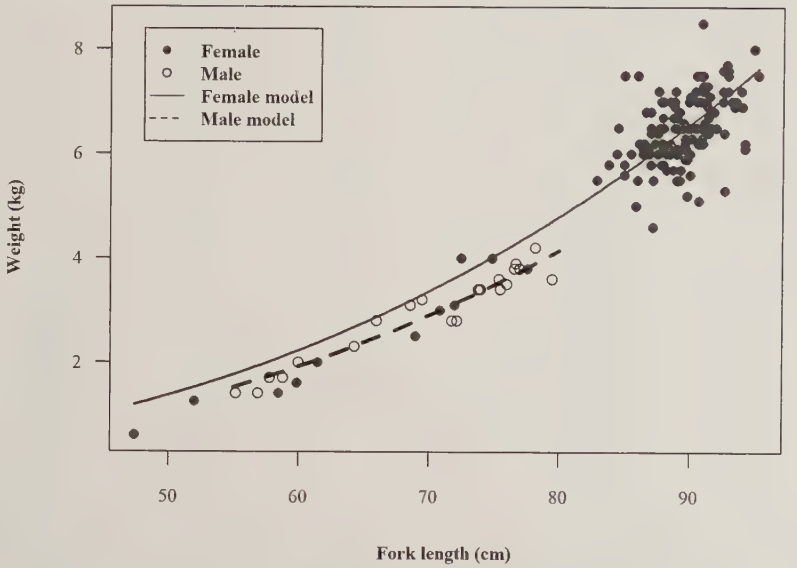


Figure 11D.–Relationship between over-the-body fork length and total weight for *Centrophorus* spp., from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Common Thresher Shark, *Alopias vulpinus*

Table 12A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for common thresher sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	149.5–264.7	240.0–470.0	23.6	1.67	0.810	284
Female	149.5–264.7	240.0–470.0				133
Male	157.7–233.6	252.5–466.1				149

Table 12B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for common thresher sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	152.0–261.0	235.8–468.0	33.3	1.69	0.957	104
Female	154.2–261.0	285.0–468.0				41
Male	152.0–233.0	235.8–423.0				63

Table 12C.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for common thresher sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	143.0–268.0	49.4–287.1	4.49E-05	2.79	11.4	1,098
Female	149.5–268.0	49.4–287.1	2.94E-05	2.87	12.1	571
Male	143.0–248.0	50.6–192.8	7.35E-05	2.70	10.5	519

Table 12D.–Relationship between over-the-body fork length (FL_{OTB}) and straight-line fork length (FL_{SL}) for common thresher sharks from the western North Atlantic Ocean in the form of $FL_{OTB} = a + b*FL_{SL}$.

Sex	CFL range	SFL range	a	b	r^2	*n*
Combined	168.0–257.2	162.7–255.0	-17.01	1.05	0.9669	20
Female	195.0–257.2	185.5–255.0				5
Male	168.0–224.5	162.7–217.5				15

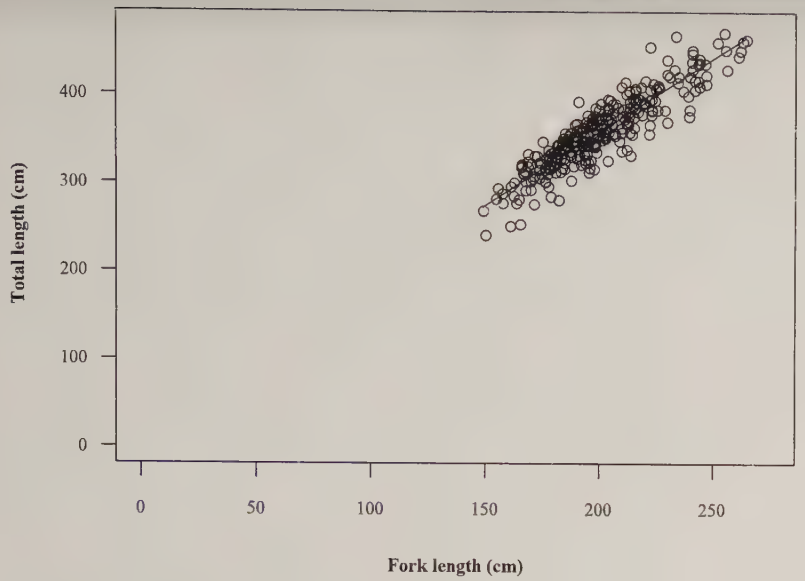


Figure 12A.–Relationship between over-the-body fork length and total length for common thresher sharks from the western North Atlantic Ocean (sexes combined).

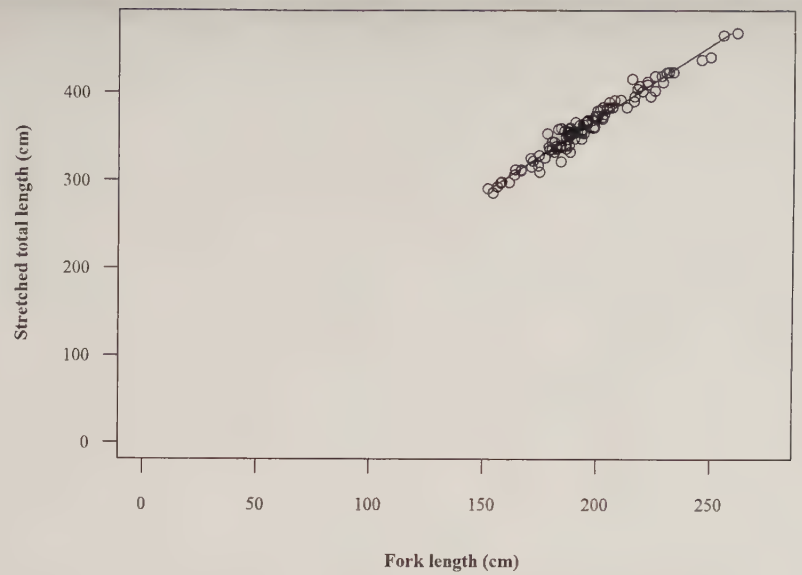


Figure 12B.–Relationship between over-the-body fork length and stretched total length for common thresher sharks from the western North Atlantic Ocean (sexes combined).

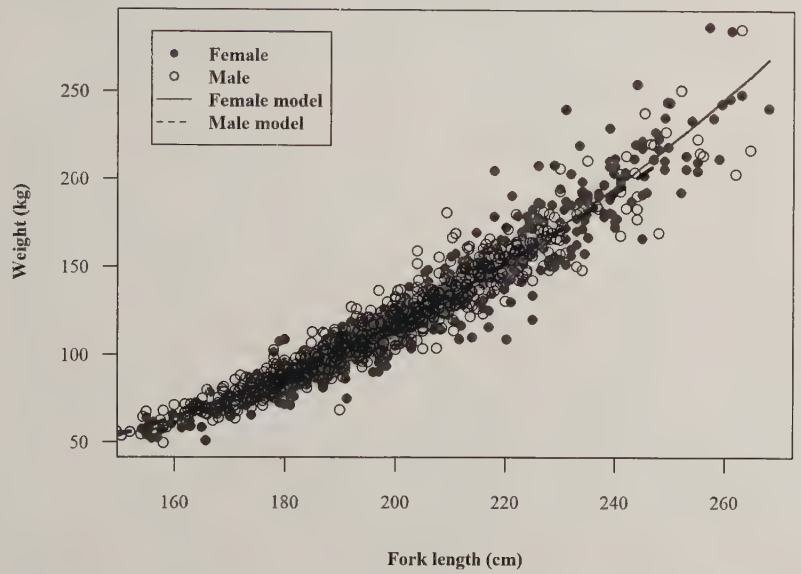


Figure 12C.–Relationship between over-the-body fork length and total weight for common thresher sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

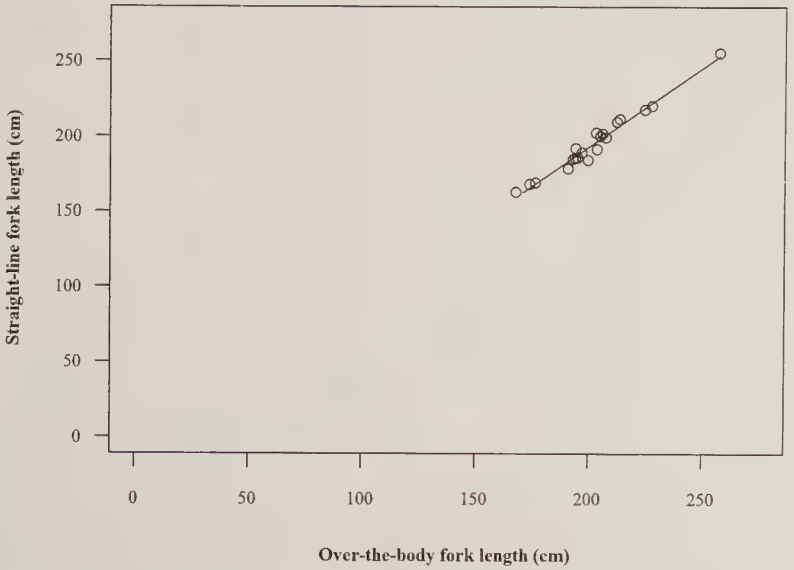


Figure 12D.–Relationship between over-the-body fork length and straight-line fork length for common thresher sharks from the western North Atlantic Ocean (sexes combined).

Dusky Shark, *Carcharhinus obscurus*

Table 13A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for dusky sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	64.3–277.0	78.0–333.0	2.11	1.19	0.993	264
Female	64.3–277.0	78.0–333.0				131
Male	74.0–276.0	89.2–330.0				133

Table 13B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for dusky sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	62.7–238.0	77.8–300.0	2.44	1.21	0.996	44
Female	62.7–221.0	77.8–276.4				28
Male	81.6–238.0	101.6–300.0				16

Table 13C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for dusky sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	127.6–238.0	115.5–217.0	-2.73	0.917	0.998	6
Female	127.6–215.0	115.1–195.0				3
Male	190.0–238.0	170.0–217.0				3

Table 13D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for dusky sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	64.3–287.0	2.04–269.9	2.68E-05	2.82	11.7	416
Female	64.3–287.0	2.04–269.9	2.44E-05	2.84	13.9	245
Male	77.5–276.0	2.16–216.4	2.12E-05	2.87	7.39	170

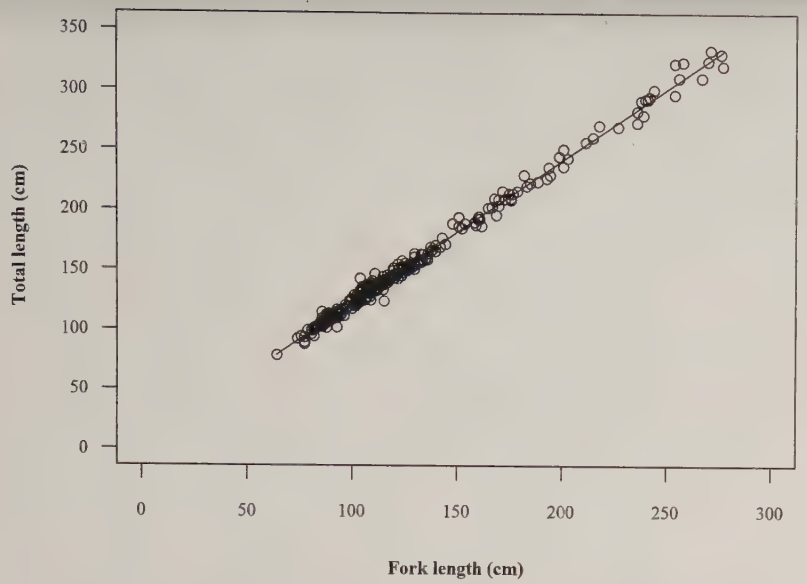


Figure 13A.–Relationship between over-the-body fork length and total length for dusky sharks from the western North Atlantic Ocean (sexes combined).

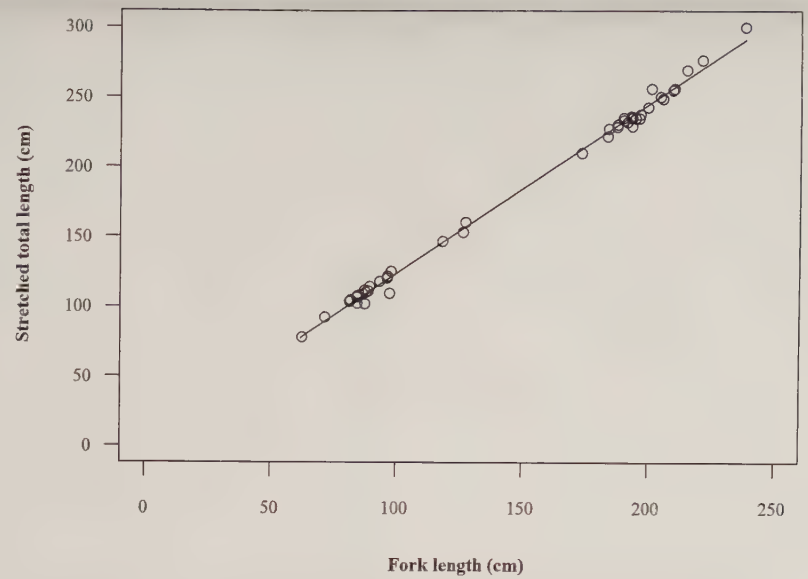


Figure 13B.–Relationship between over-the-body fork length and stretched total length for dusky sharks from the western North Atlantic Ocean (sexes combined).

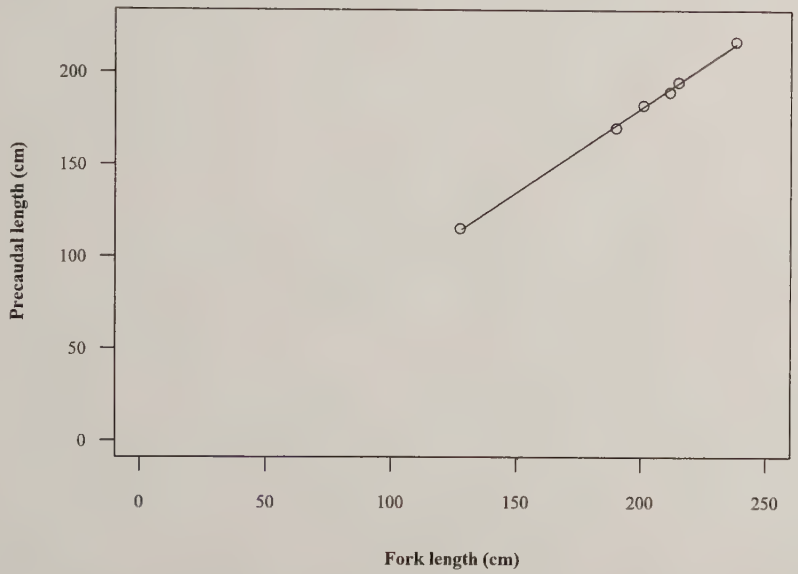


Figure 13C.–Relationship between over-the-body fork length and precaudal length for dusky sharks from the western North Atlantic Ocean (sexes combined).

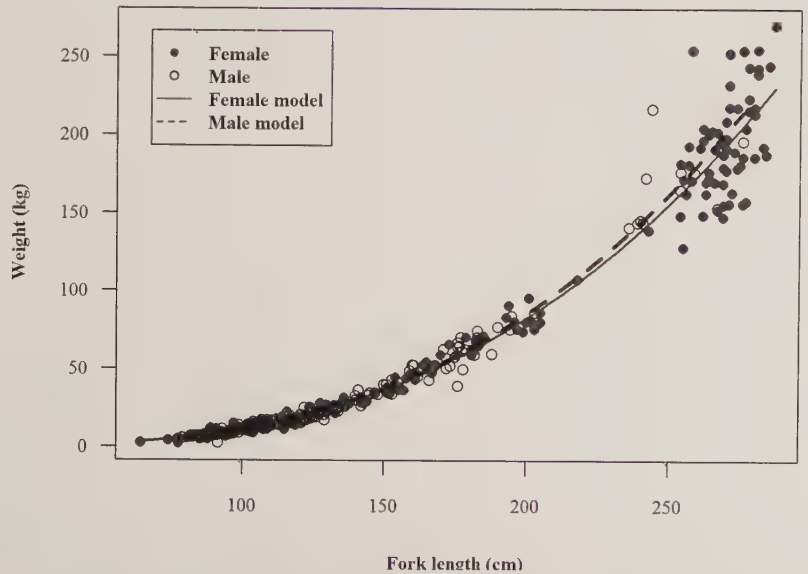


Figure 13D.–Relationship between over-the-body fork length and total weight for dusky sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Finetooth Shark, *Carcharhinus isodon*

Table 14A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for finetooth sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	41.5–129.0	49.5–154.0	-0.786	1.22	0.988	100
Female	42.0–129.0	49.5–154.0				44
Male	41.5–118.0	50.0–145.0				54

Table 14B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for finetooth sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	25.5–137.0	36.9–164.4	0.336	1.25	0.999	7,265
Female	25.5–137.0	36.9–164.4				3,754
Male	34.7–126.5	40.0–157.1				3,464

Table 14C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for finetooth sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	35.0–137.0	32.0–120.0	-0.117	0.905	0.998	934
Female	38.5–137.0	35.0–120.0				454
Male	35.0–118.5	32.0–106.0				473

Table 14D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for finetooth sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	35.0–126.5	0.07–21.7	1.11E-05	2.99	0.706	755
Female	41.0–126.5	0.50–21.7	1.13E-05	2.99	0.818	367
Male	35.0–118.5	0.07–17.0	1.33E-05	2.94	0.553	381

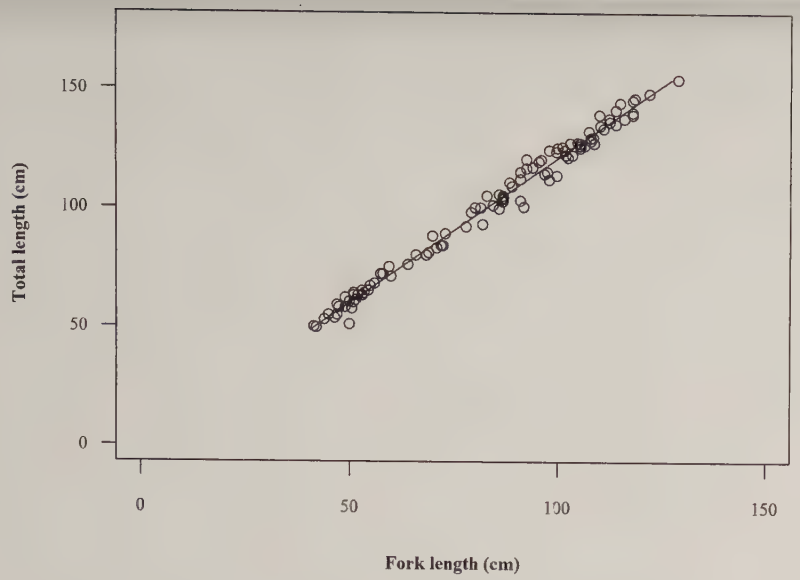


Figure 14A.–Relationship between over-the-body fork length and total length for finetooth sharks from the western North Atlantic Ocean (sexes combined).

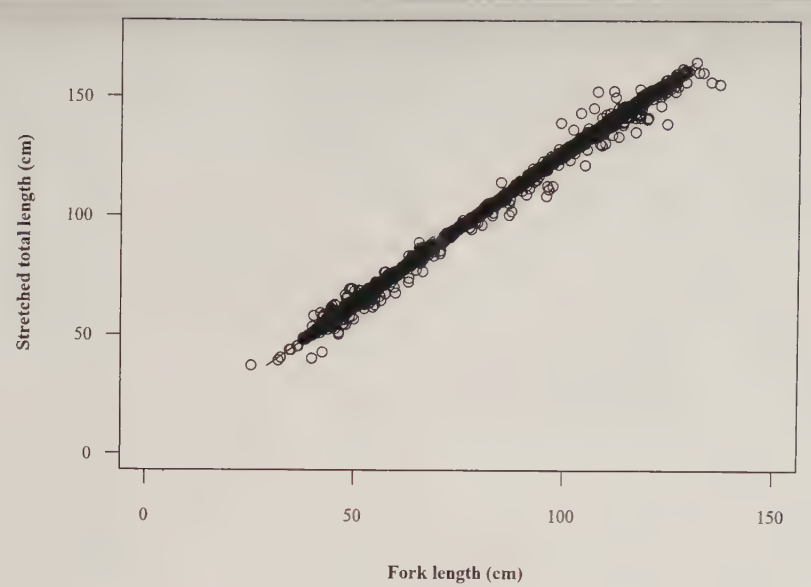


Figure 14B.–Relationship between over-the-body fork length and stretched total length for finetooth sharks from the western North Atlantic Ocean (sexes combined).

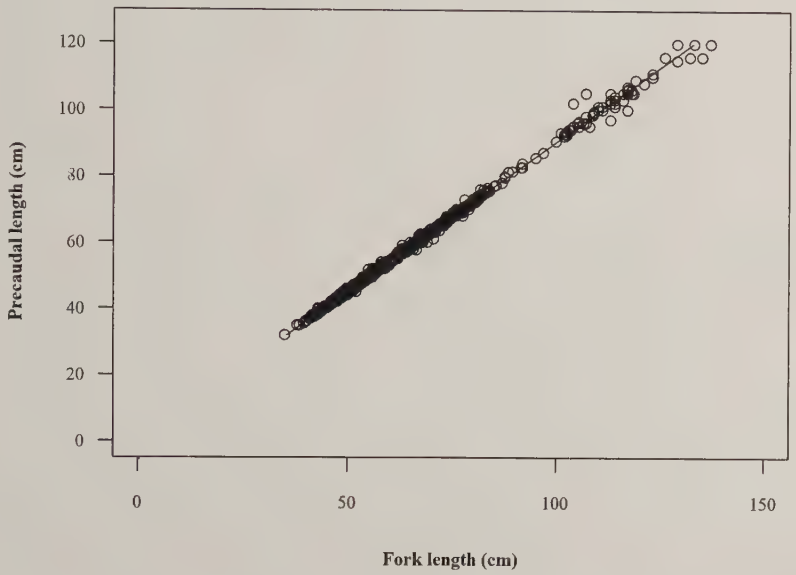


Figure 14C.–Relationship between over-the-body fork length and precaudal length for finetooth sharks from the western North Atlantic Ocean (sexes combined).

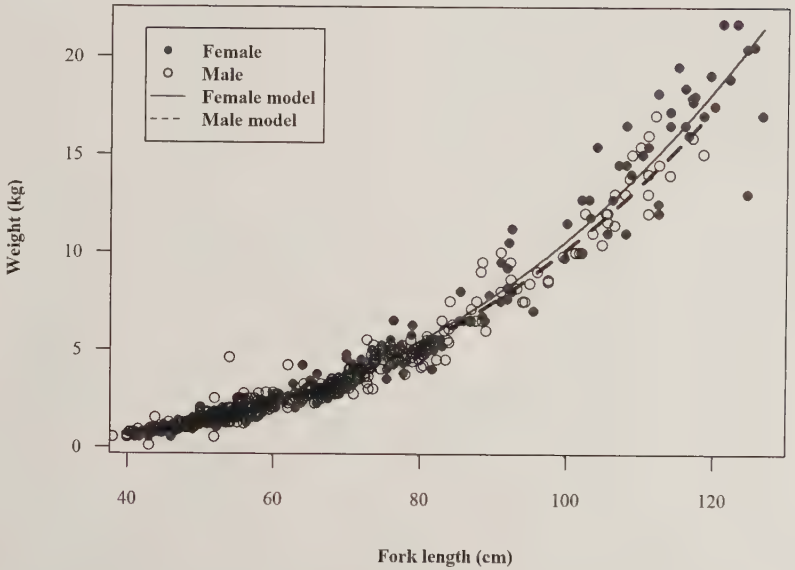


Figure 14D.–Relationship between over-the-body fork length and total weight for finetooth sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Great Hammerhead, *Sphyrna mokarran*

Table 15A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for great hammerheads from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	91.7–236.8	117.0–305.0	9.14	1.23	0.983	50
Female	91.7–236.8	117.0–291.5				23
Male	93.4–234.9	124.5–305.0				27

Table 15B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for great hammerheads from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	85.5–320.0	113.5–400.0	14.1	1.23	0.989	58
Female	85.5–320.0	115.5–400.0				35
Male	93.4–282.0	113.5–350.0				21

Table 15C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for great hammerheads from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	85.5–282.0	78.0–251.0	1.65	0.896	0.996	47
Female	85.5–253.0	78.0–229.0				27
Male	93.4–282.0	84.5–251.0				20

Table 15D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for great hammerheads from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	85.5–238.0	6.4–160.0	1.69E-05	2.91	11.3	50
Female	85.5–236.8	6.4–160.0	9.28E-06	3.03	10.6	24
Male	91.0–238.0	8.0–160.0	2.48E-05	2.84	12.0	26

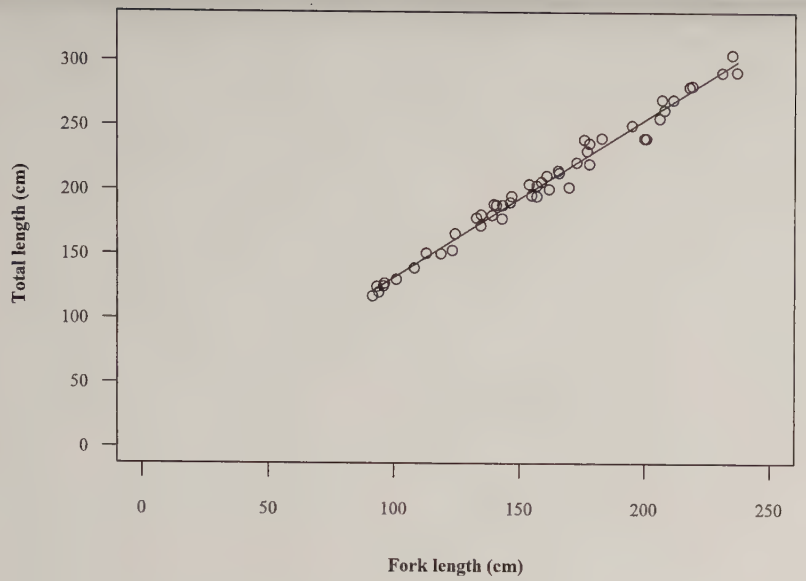


Figure 15A.–Relationship between over-the-body fork length and total length for great hammerheads from the western North Atlantic Ocean (sexes combined).

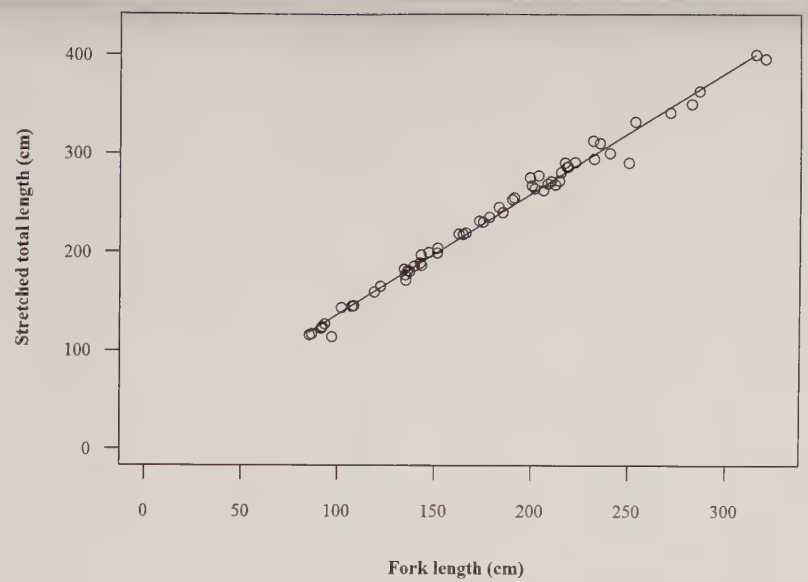


Figure 15B.–Relationship between over-the-body fork length and stretched total length for great hammerheads from the western North Atlantic Ocean (sexes combined).

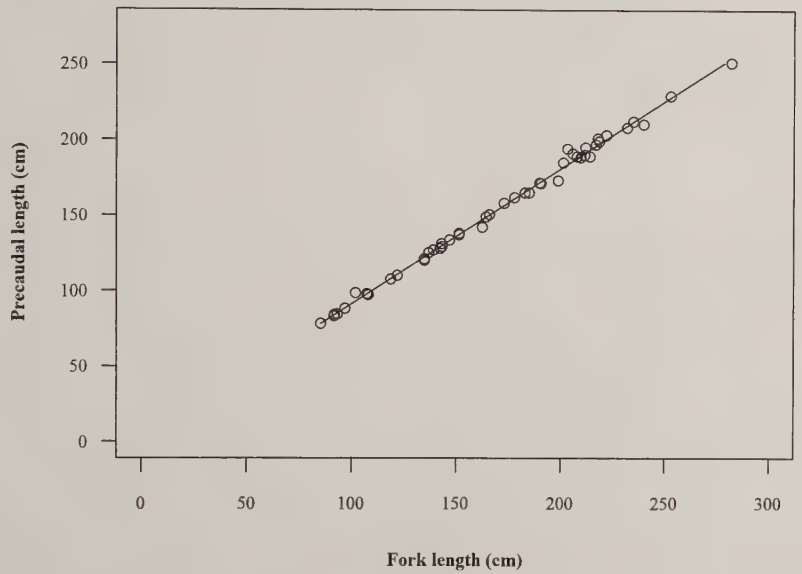


Figure 15C.–Relationship between over-the-body fork length and precaudal length for great hammerheads from the western North Atlantic Ocean (sexes combined).

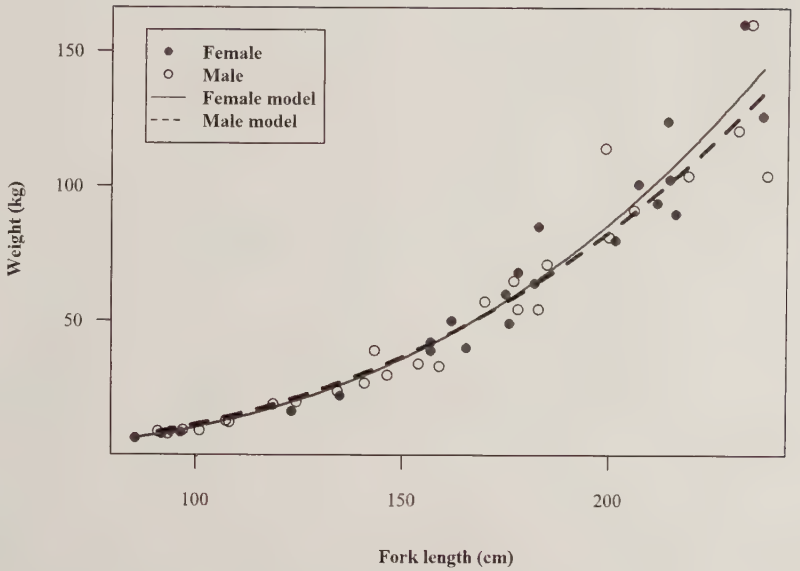


Figure 15D.–Relationship between over-the-body fork length and total weight for great hammerheads from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Lemon Shark, *Negaprion brevirostris*

Table 16A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for lemon sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	59.0–221.0	69.0–266.0	-1.88	1.20	0.994	22
Female	60.0–208.0	72.0–248.0				12
Male	59.0–221.0	69.0–266.0				9

Table 16B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for lemon sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	49.8–260.0	61.3–320.0	-2.65	1.23	0.991	113
Female	54.5–260.0	65.5–320.0				42
Male	49.8–240.0	61.3–290.0				64

Table 16C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for lemon sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	54.5–235.0	50.0–210.0	-2.09	0.923	0.996	35
Female	54.5–224.0	50.0–204.0				16
Male	59.0–235.0	54.0–210.0				18

Table 16D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for lemon sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	54.5–222.0	1.81–118.0	5.56E-05	2.67	7.28	18
Female	54.5–222.0	1.81–118.0	1.91E-05	2.88	4.47	13
Male	59.0–217.0	1.81–75.0	7.59E-04	2.14	1.94	5

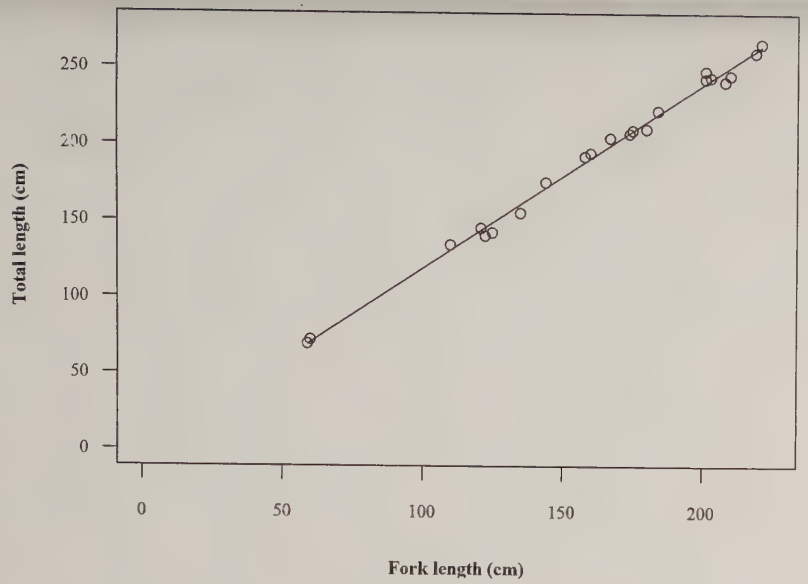


Figure 16A.–Relationship between over-the-body fork length and total length for lemon sharks from the western North Atlantic Ocean (sexes combined).

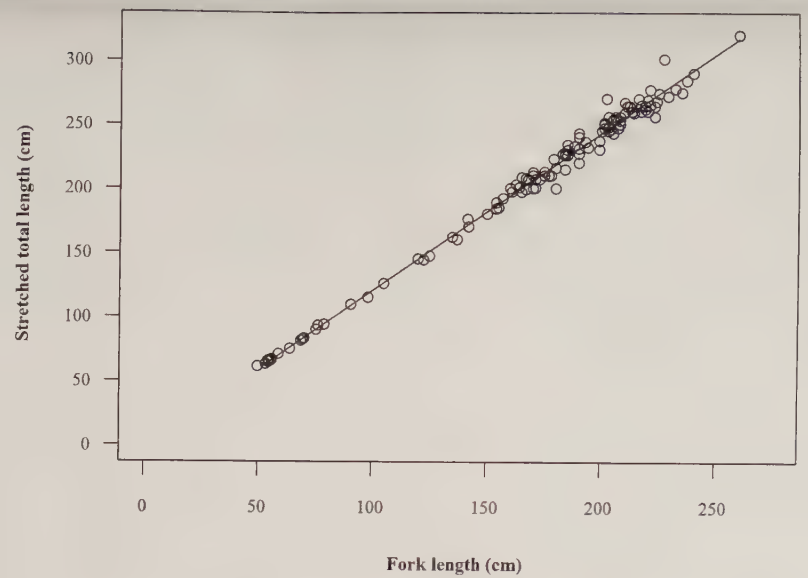


Figure 16B.–Relationship between over-the-body fork length and stretched total length for lemon sharks from the western North Atlantic Ocean (sexes combined).

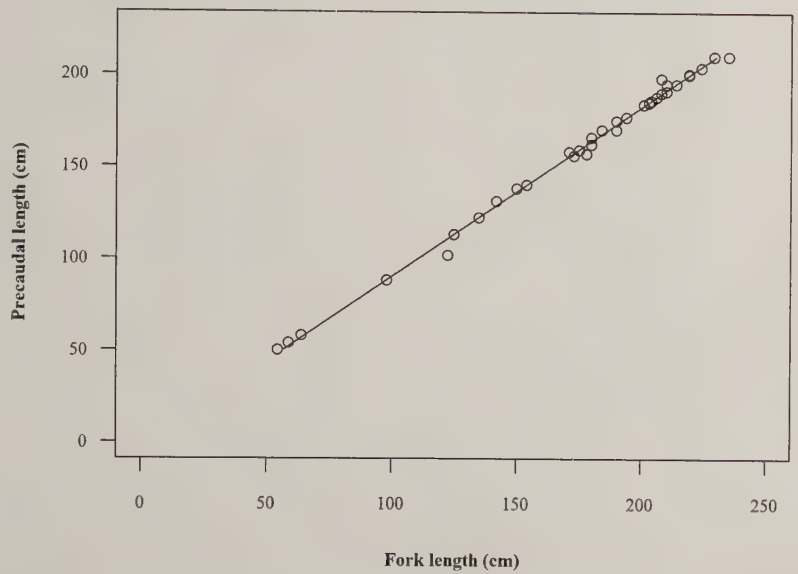


Figure 16C.–Relationship between over-the-body fork length and precaudal length for lemon sharks from the western North Atlantic Ocean (sexes combined).

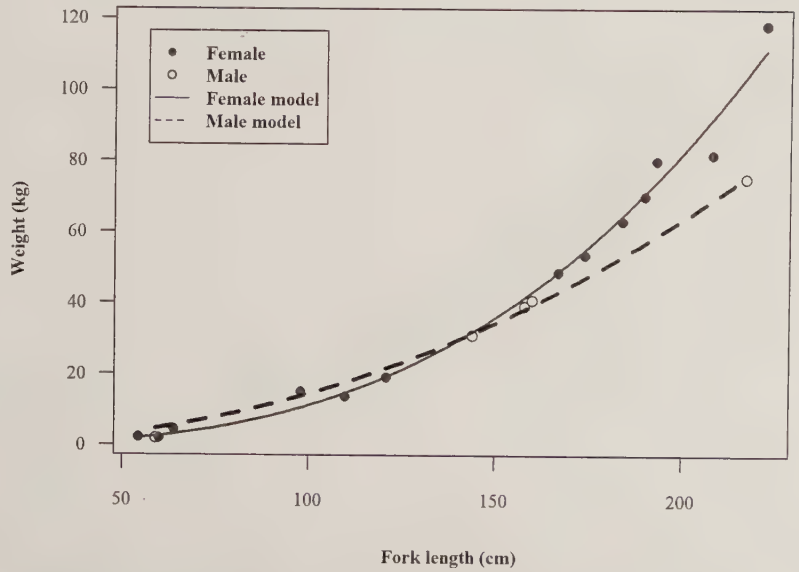


Figure 16D.–Relationship between over-the-body fork length and total weight for lemon sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Mustelus spp.

Table 17A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for *Mustelus* spp., from the Gulf of Mexico in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	48.0–125.5	53.9–141.0	3.04	1.10	0.983	1,190
Female	48.0–125.5	56.0–141.0				874
Male	48.7–111.5	53.9–132				312

Table 17B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for *Mustelus* spp., from the Gulf of Mexico in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	45.0–121.2	52.5–138.5	2.96	1.12	0.989	534
Female	48.2–121.2	56.7–138.5				383
Male	45.0–103.5	52.5–120.5				141

Table 17C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for *Mustelus* spp., from the Gulf of Mexico in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	48.2–121.2	43.9–112.9	-0.546	0.934	0.997	445
Female	48.2–121.2	43.9–112.9				317
Male	48.7–102.5	45.2–96.0				128

Table 17D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for *Mustelus* spp., from the Gulf of Mexico in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	48.0–125.5	0.45–12.5	1.64E-06	3.30	0.753	1,414
Female	48.0–125.5	0.45–12.5	3.53E-06	3.13	0.814	1,029
Male	48.7–111.5	0.5–10.8	3.37E-06	3.12	0.466	369

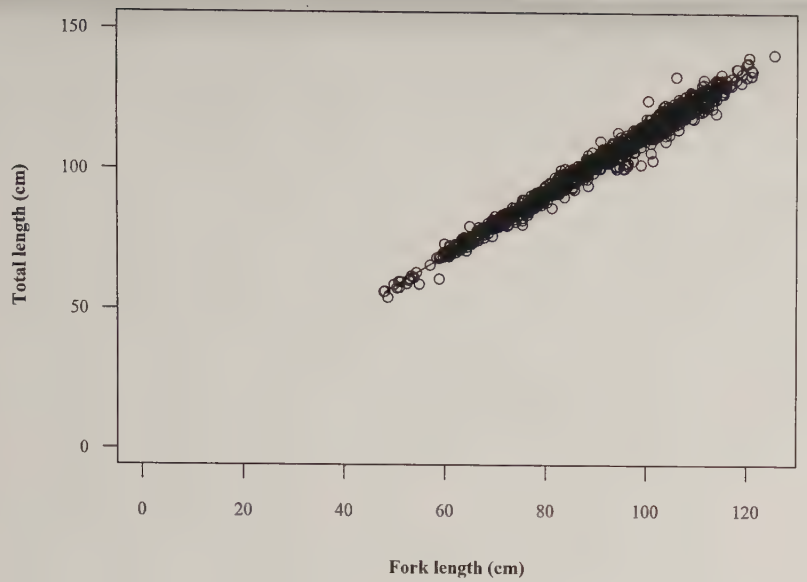


Figure 17A.–Relationship between over-the-body fork length and total length for *Mustelus* spp., from the western North Atlantic Ocean (sexes combined).

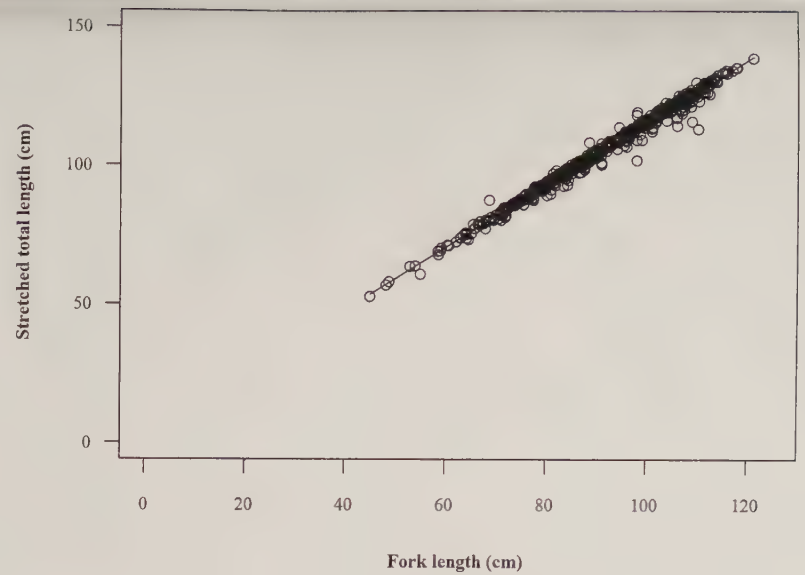


Figure 17B.–Relationship between over-the-body fork length and stretched total length for *Mustelus* spp., from the western North Atlantic Ocean (sexes combined).

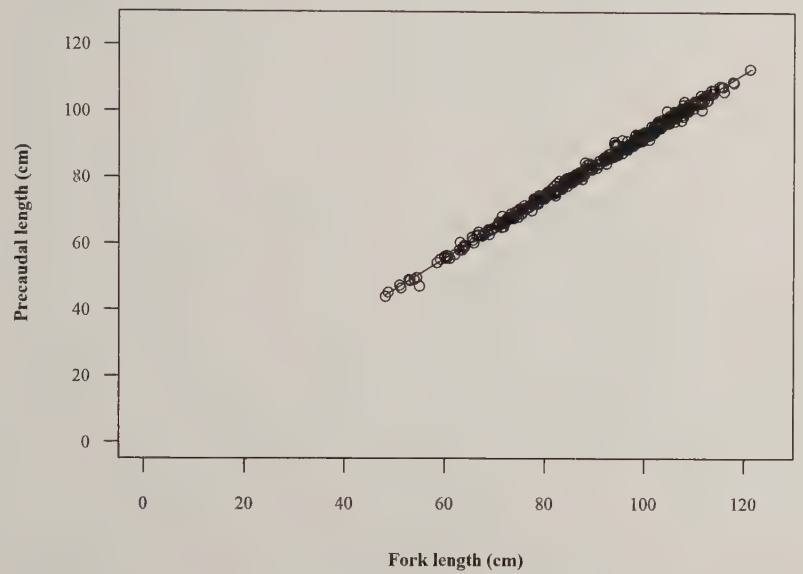


Figure 17C.–Relationship between over-the-body fork length and precaudal length for *Mustelus* spp., from the western North Atlantic Ocean (sexes combined).

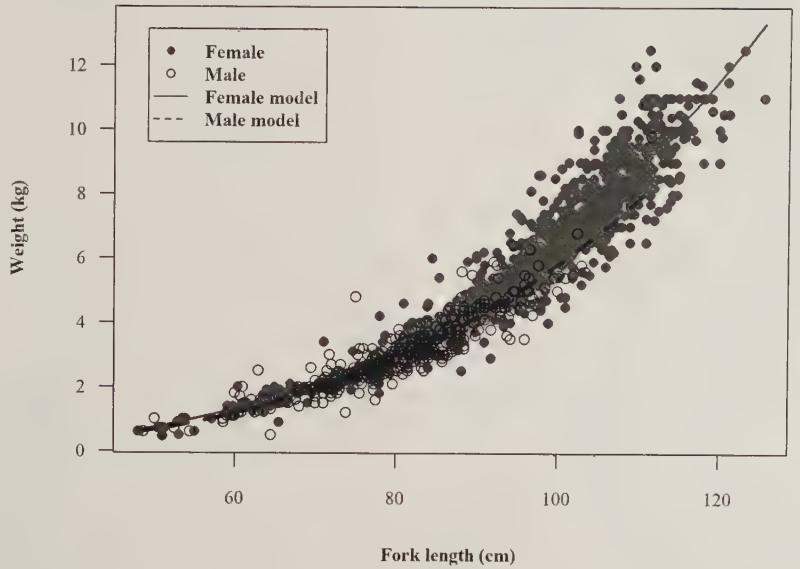


Figure 17D.–Relationship between over-the-body fork length and total weight for *Mustelus* spp., from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Night Shark, *Carcharhinus signatus*

Table 18A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for night sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	46.0–213.0	53.4–247.0	1.55	1.17	0.995	67
Female	52.4–213.0	63.6–247.0				33
Male	46.0–195.0	53.4–235.0				34

Table 18B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for night sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	51.7–80.0	63.5–99.5	0.738	1.23	0.986	12
Female						7
Male						5

Table 18C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for night sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	51.7–80.0	46.8–73.0	-1.73	0.934	0.998	9
Female						6
Male						3

Table 18D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for night sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	46.0–213.0	0.8–103.9	4.36E-06	3.17	2.63	158
Female	52.4–213.0	1.2–103.9	4.44E-06	3.17	2.67	72
Male	46.0–195.0	0.8–64.0	3.00E-05	2.76	1.63	85

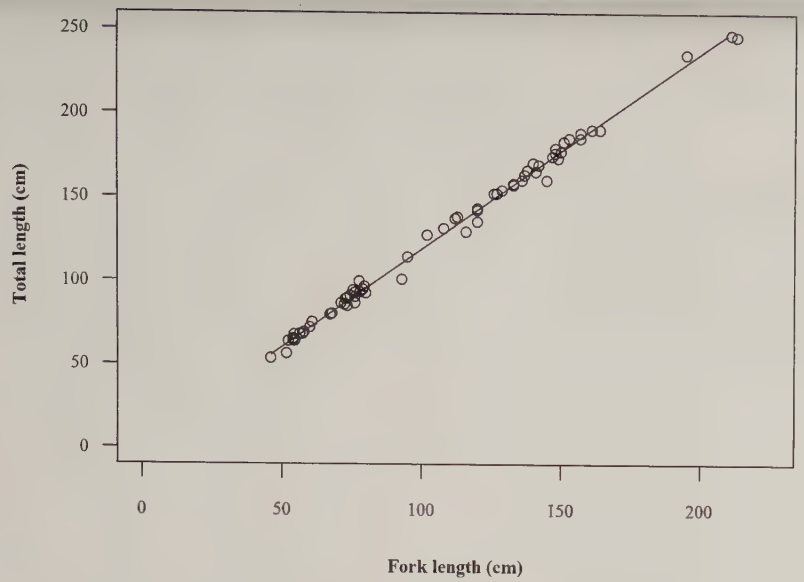


Figure 18A.–Relationship between over-the-body fork length and total length for night sharks from the western North Atlantic Ocean (sexes combined).

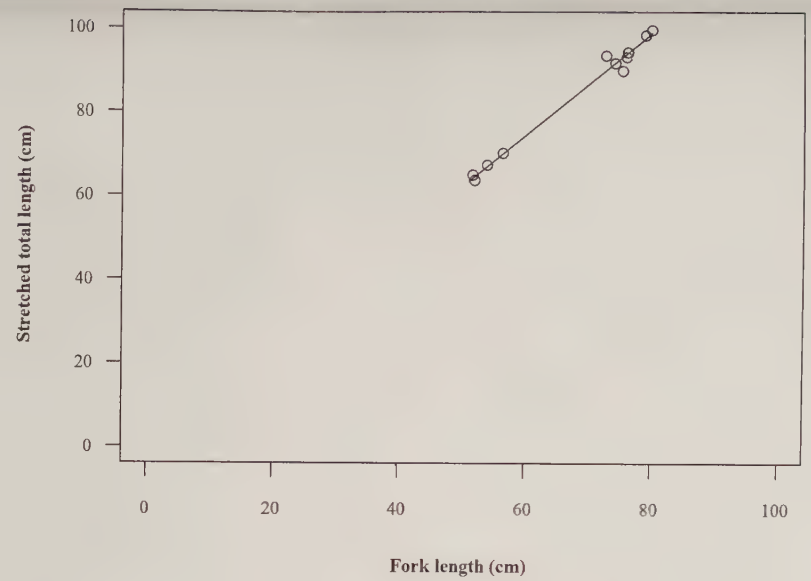


Figure 18B.–Relationship between over-the-body fork length and stretched total length for night sharks from the western North Atlantic Ocean (sexes combined).

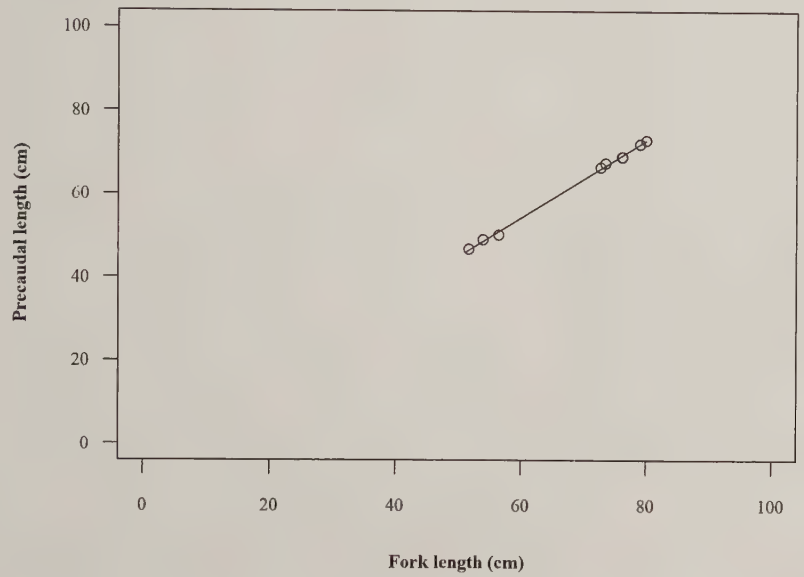


Figure 18C.–Relationship between over-the-body fork length and precaudal length for night sharks from the western North Atlantic Ocean (sexes combined).

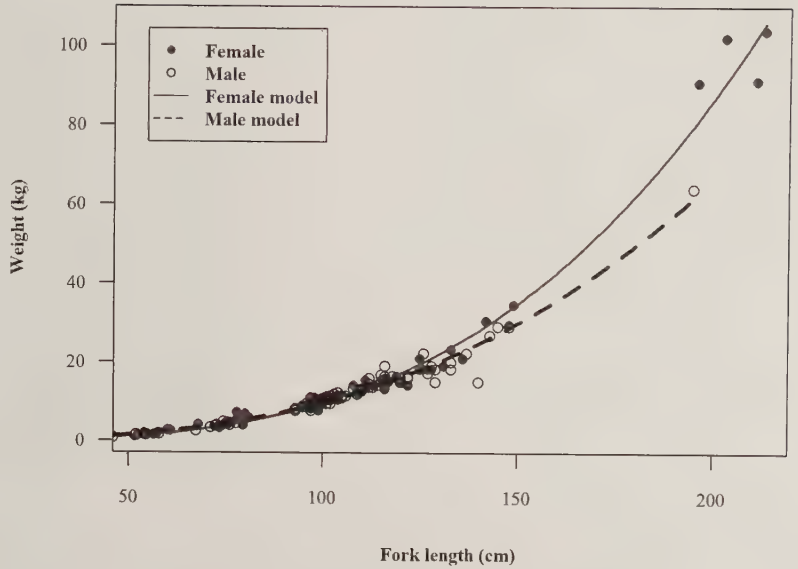
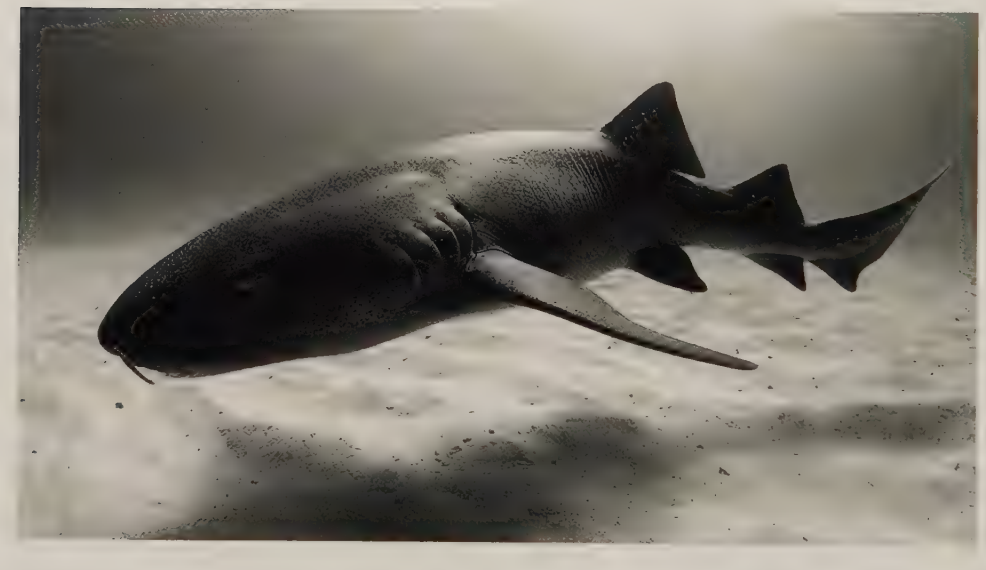


Figure 18D.–Relationship between over-the-body fork length and total weight for night sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Nurse Shark, *Ginglymostoma cirratum*

Table 19.–Relationship between over-the-body fork length (TL_{OTB}) and total weight (W) for nurse sharks from the western North Atlantic Ocean in the form of $W = aTL_{OTB}^{b}$.

Sex	TL range	Weight range	a	b	RSE	*n*
Combined	58.5–263.0	1.7–120.0	8.61E-04	2.085	16.3	58
Female	58.5–262.0	1.7–106.0	5.94E-04	2.143	15.4	26
Male	143.0–263.0	16.5–120.0	1.38E-03	2.007	16.9	31



Nurse shark. Photo: Joe Romeiro.

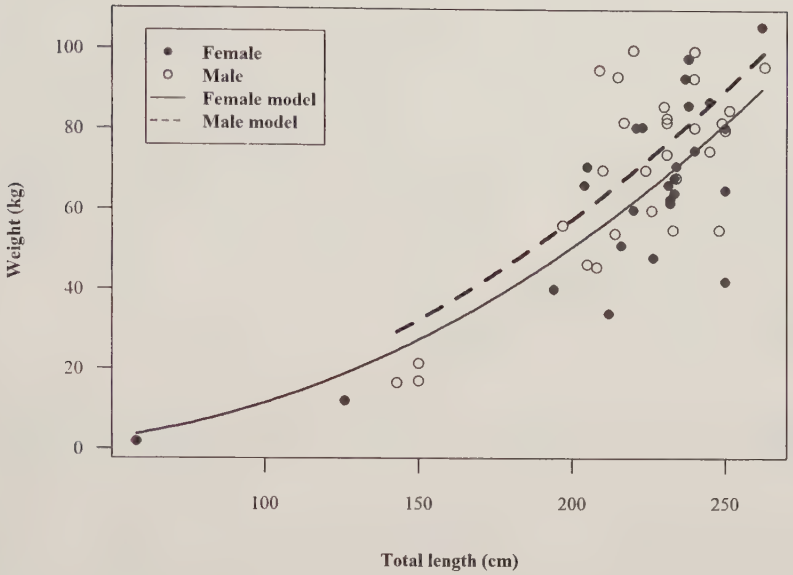


Figure 19.–Relationship between over-the-body total length and total weight for nurse sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Porbeagle, *Lamna nasus*

Table 20A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for porbeagles from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b^{*}FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	85.5–260.5	95.0–293.0	0.730	1.12	0.995	668
Female	94.0–260.5	102.5–293.0				311
Male	85.5–246.0	95.0–281.0				357

Table 20B.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for porbeagles from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	85.5–260.5	7.0–278.2	1.84E-06	3.36	10.7	508
Female	94.0–260.5	12.0–278.2	1.87E-06	3.36	12.5	245
Male	85.5–246.0	7.0–198.0	1.63E-05	2.94	6.87	263

Table 20C.–Relationship between over-the-body fork length (FL_{OTB}) and straight-line fork length (FL_{SL}) for porbeagles from the western North Atlantic Ocean in the form of $FL_{OTB} = a + b^{*}FL_{SL}$.

Sex	CFL range	SFL range	a	b	r^2	*n*
Combined	86.2–264.0	83.0–253.5	-0.1692	0.9595	0.9958	188
Female	86.2–264.0	84.0–253.5				91
Male	88.0–235.0	83.0–231.5				97

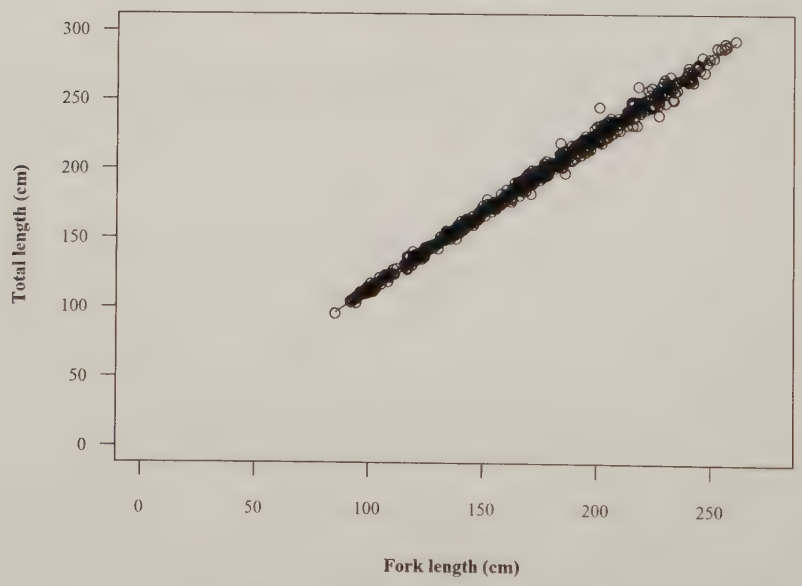


Figure 20A.–Relationship between over-the-body fork length and total length for porbeagles from the western North Atlantic Ocean (sexes combined).

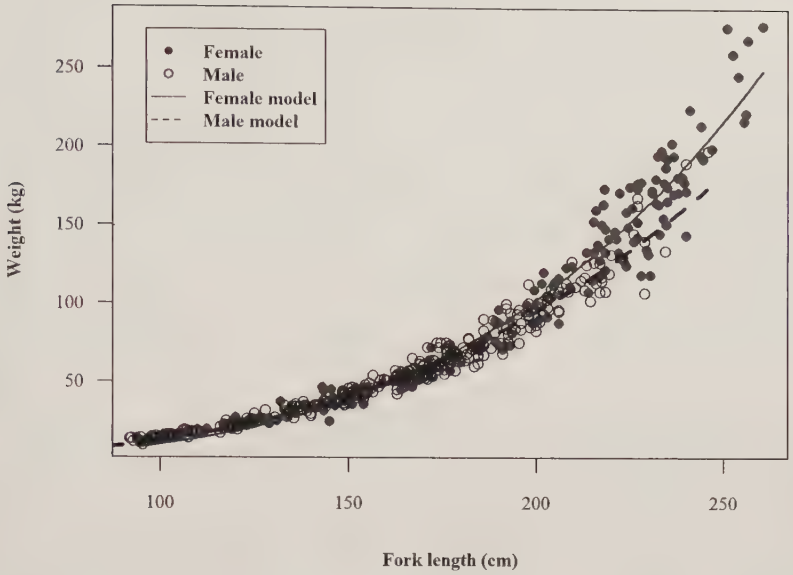


Figure 20B.–Relationship between over-the-body fork length and total weight for porbeagles from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

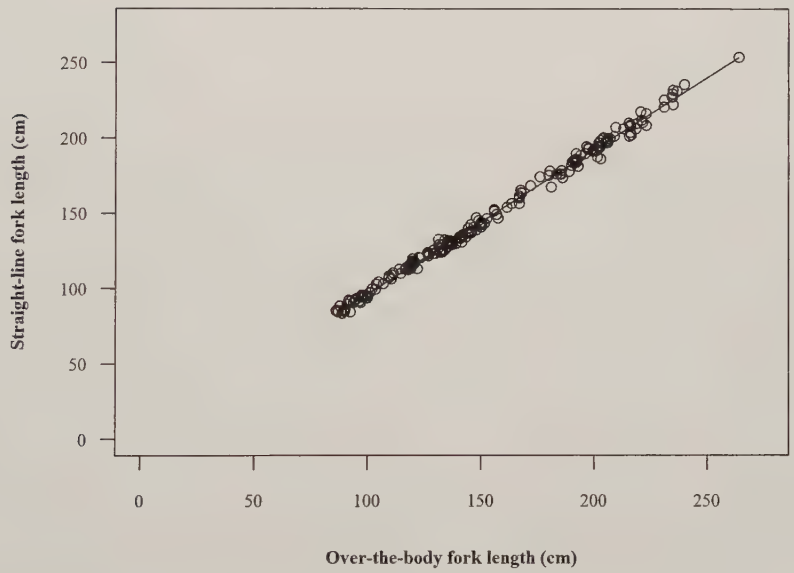


Figure 20C.–Relationship between over-the-body fork length and straight-line fork length for porbeagles from the western North Atlantic Ocean (sexes combined).

Sand Tiger, *Carcharias taurus*

Table 21A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for sand tigers from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	59.0–232.0	67.0–273.0	4.62	1.14	0.984	114
Female	60.0–232.0	69.0–273.0				60
Male	59.0–212.0	67.0–247.0				54

Table 21B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for sand tigers from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	78.0–294.0	95.9–335.0	9.98	1.15	0.979	65
Female	111.0–294.0	136.8–335.0				27
Male	78.0–212.0	95.9–254.0				38

Table 21C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for sand tigers from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	105.0–226.0	95.0–198.0	-2.06	0.885	0.989	87
Female	105.0–226.0	95.0–198.0				41
Male	112.0–212.0	98.0–192.0				46

Table 21D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for sand tigers from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	59.0–230.0	2.6–144.2	2.59E-06	3.25	7.58	26
Female	60.0–230.0	2.6–144.2	1.99E-06	3.32	5.01	15
Male	59.0–217.0	2.6–86.2	8.69E-05	2.57	5.13	11

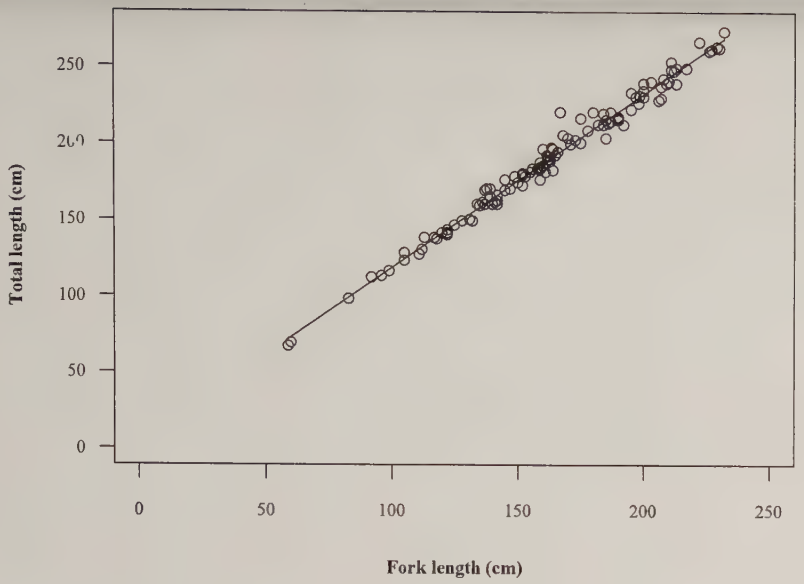


Figure 21A.–Relationship between over-the-body fork length and total length for sand tigers from the western North Atlantic Ocean (sexes combined).

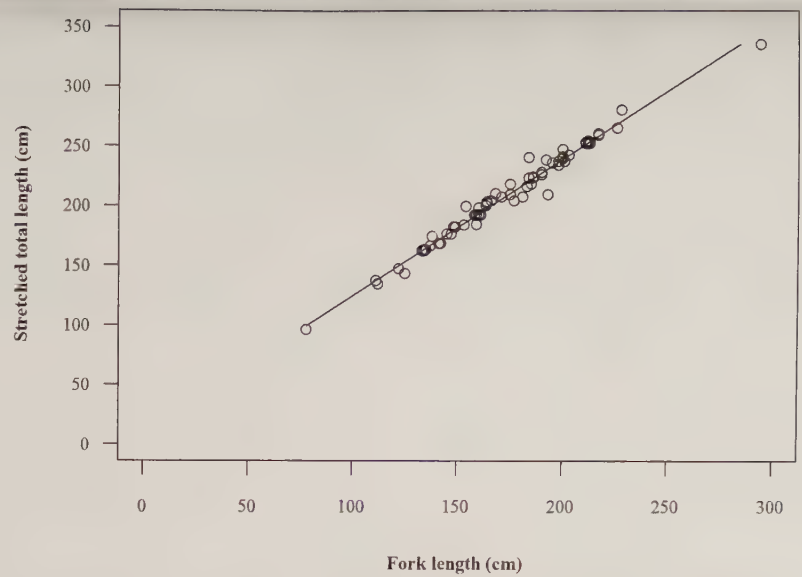


Figure 21B.–Relationship between over-the-body fork length and stretched total length for sand tigers from the western North Atlantic Ocean (sexes combined).

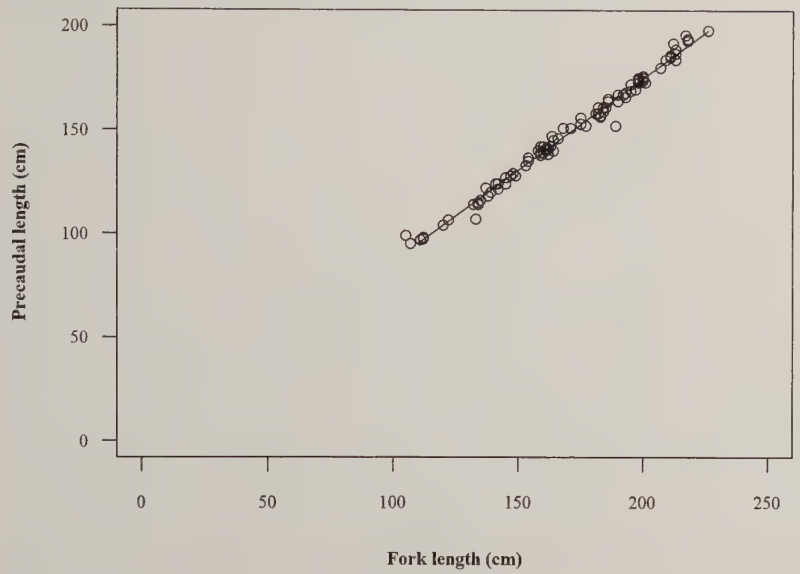


Figure 21C.–Relationship between over-the-body fork length and precaudal length for sand tigers from the western North Atlantic Ocean (sexes combined).

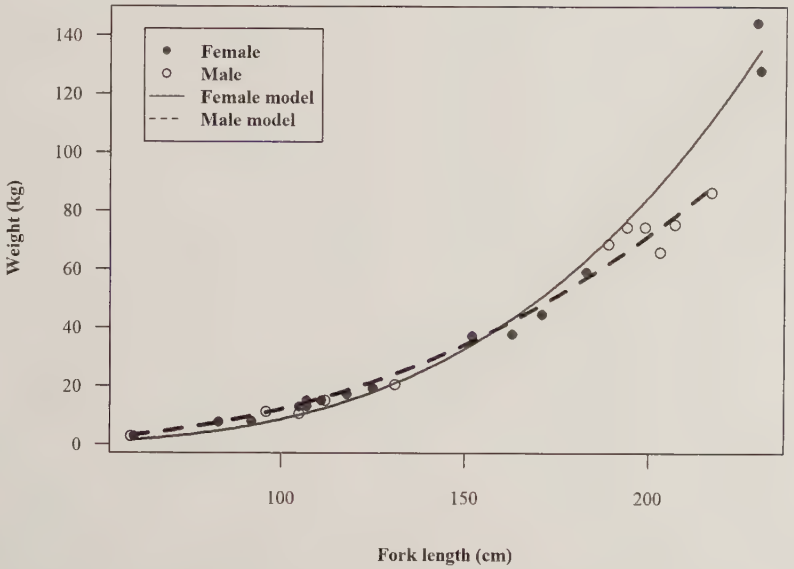


Figure 21D.–Relationship between over-the-body fork length and total weight for sand tigers from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Sandbar Shark, *Carcharhinus plumbeus*

Table 22A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for sandbar sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	37.0–216.0	43.0–249.0	-1.11	1.20	0.996	8,961
Female	39.0–216.0	47.0–249.0				4,941
Male	37.0–180.0	43.0–215.0				3,999

Table 22B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for sandbar sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	34.4–196.4	35.0–241.0	1.09	1.22	0.996	7,154
Female	34.4–196.4	45.8–241.0				3,721
Male	35.4–195.0	35.0–238.5				3,340

Table 22C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for sandbar sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	38.0–196.4	34.0–179.2	-0.023	0.904	0.998	1,900
Female	39.0–196.4	36.0–179.2				1,128
Male	38.0–195.0	34.0–176.0				762

Table 22D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for sandbar sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	37.0–201.0	0.32–104.3	1.20E-05	2.99	3.03	8,321
Female	39.0–201.0	0.60–104.3	1.32E-05	2.98	3.66	4,415
Male	37.0–183.0	0.32–70.0	2.31E-05	2.85	1.91	3,841

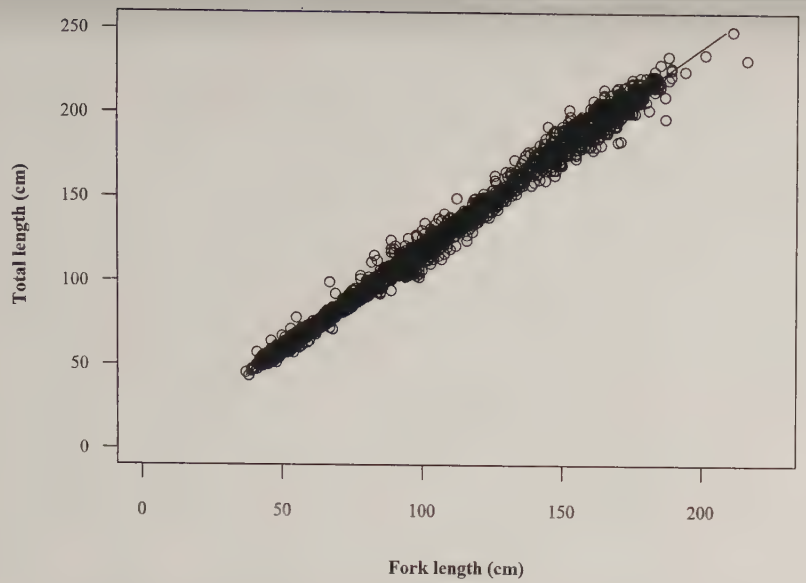


Figure 22A.–Relationship between over-the-body fork length and total length for sandbar sharks from the western North Atlantic Ocean (sexes combined).

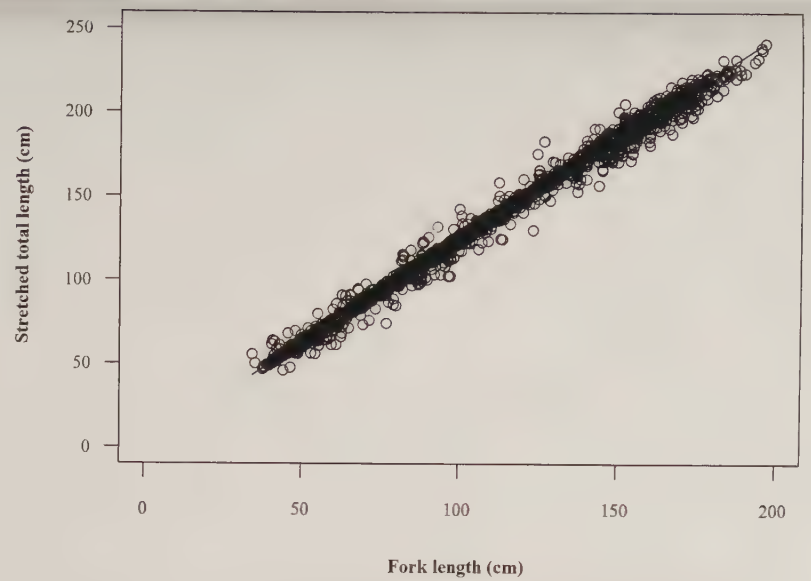


Figure 22B.–Relationship between over-the-body fork length and stretched total length for sandbar sharks from the western North Atlantic Ocean (sexes combined).

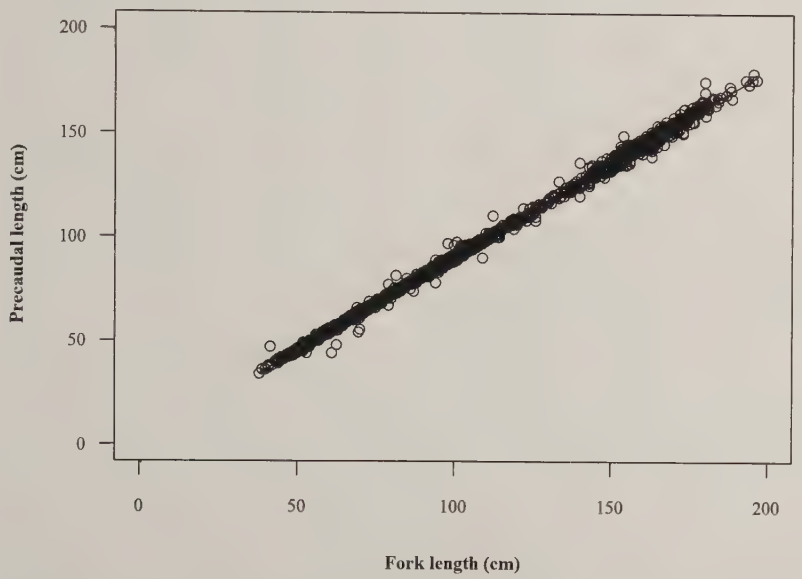


Figure 22C.–Relationship between over-the-body fork length and precaudal length for sandbar sharks from the western North Atlantic Ocean (sexes combined).

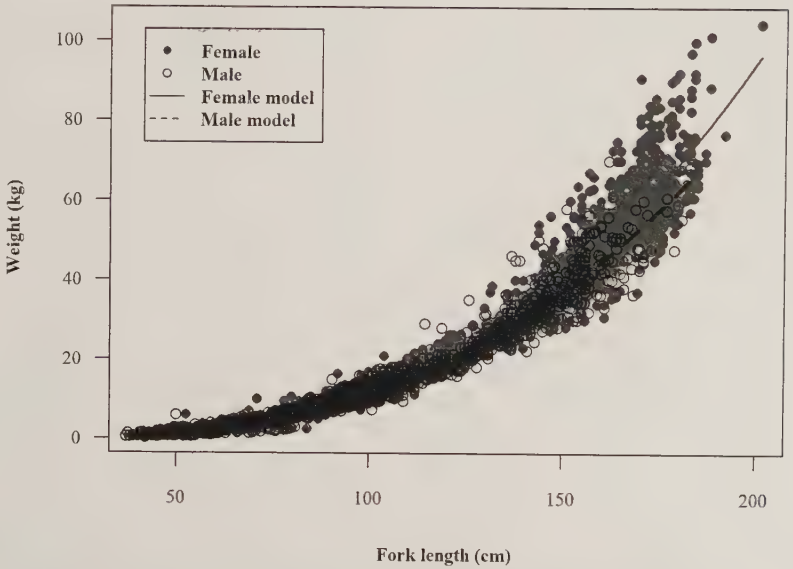


Figure 22D.–Relationship between over-the-body fork length and total weight for sandbar sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Scalloped Hammerhead, *Sphyrna lewini*

Table 23A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for scalloped hammerheads from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	30.5–250.0	39.5–316.0	0.218	1.28	0.995	534
Female	30.5–216.0	39.5–278.0				245
Male	32.0–250.0	40.5–316.0				284

Table 23B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for scalloped hammerheads from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	26.0–218.0	33.7–284.0	0.596	1.31	0.997	1,969
Female	27.8–185.0	36.8–242.0				929
Male	26.0–218.0	33.7–284.0				1,021

Table 23C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for scalloped hammerheads from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	29.0–212.2	24.0–192.5	-0.265	0.909	0.999	467
Female	29.0–150.0	24.0–142.0				201
Male	29.0–212.2	25.5–192.5				258

Table 23D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for scalloped hammerheads from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	29.0–250.0	0.15–165.6	1.17E-05	2.99	4.89	959
Female	29.0–243.0	0.20–165.6	6.03E-06	3.12	4.01	466
Male	29.0–250.0	0.15–158.8	1.78E-05	2.91	5.43	487

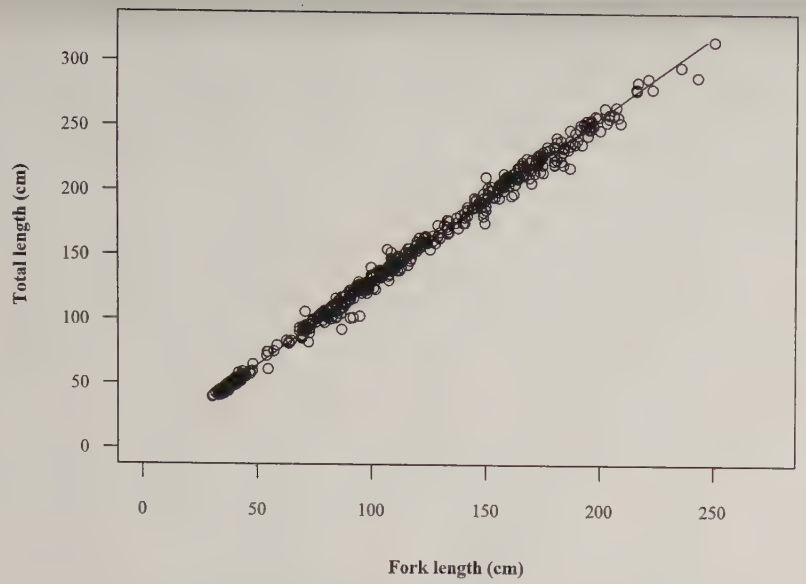


Figure 23A.–Relationship between over-the-body fork length and total length for scalloped hammerheads from the western North Atlantic Ocean (sexes combined).

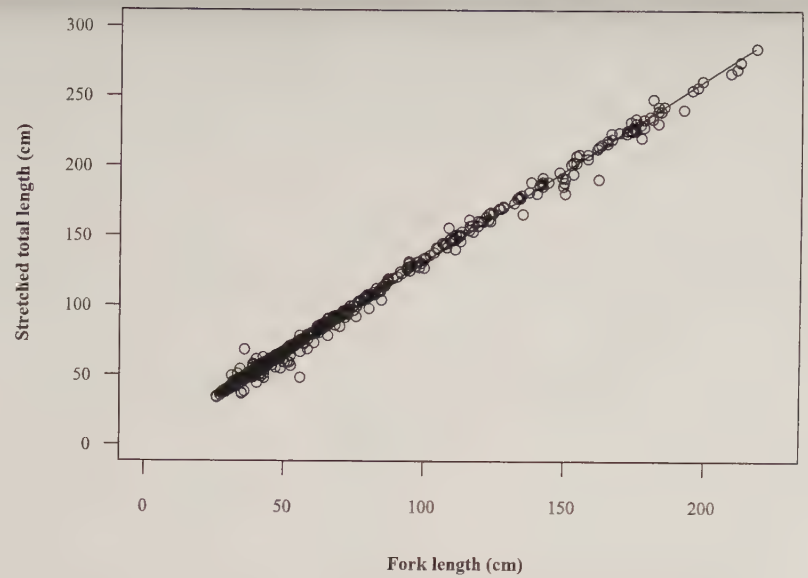


Figure 23B.–Relationship between over-the-body fork length and stretched total length for scalloped hammerheads from the western North Atlantic Ocean (sexes combined).

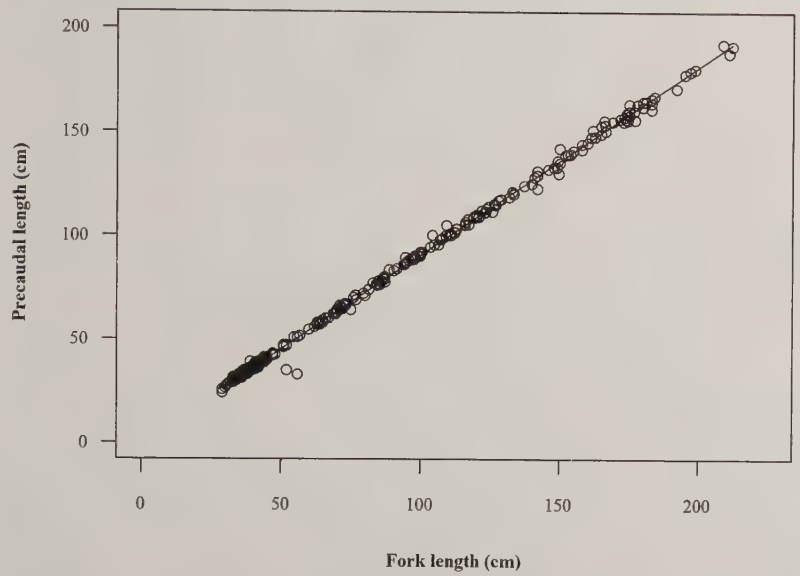


Figure 23C.–Relationship between over-the-body fork length and precaudal length for scalloped hammerheads from the western North Atlantic Ocean (sexes combined).

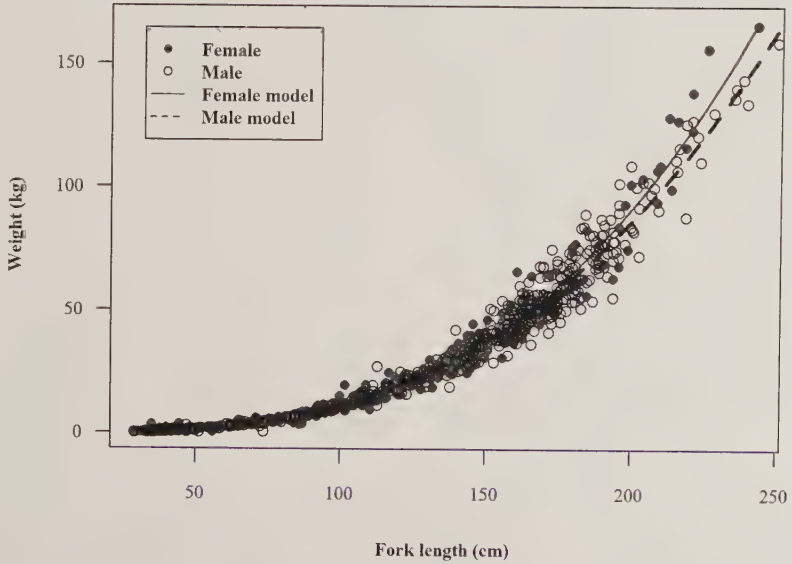


Figure 23D.–Relationship between over-the-body fork length and total weight for scalloped hammerheads from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Shortfin Mako, *Isurus oxyrinchus*

Table 24A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for shortfin makos from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	65.0–338.0	70.0–368.0	1.39	1.08	0.996	321
Female	65.0–338.0	70.0–368.0				149
Male	70.0–260.0	77.0–290.2				168

Table 24B.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for shortfin makos from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	65.0–338.0	2.3–553.8	6.48E-06	3.10	9.19	3,948
Female	65.0–338.0	2.7–553.8	5.40E-06	3.14	9.93	1,906
Male	70.0–278.7	2.3–230.0	1.25E-05	2.97	8.11	1,989

Table 24C.–Relationship between over-the-body fork length (FL_{OTB}) and straight-line fork length (FL_{SL}) for shortfin makos from the western North Atlantic Ocean in the form of $FL_{OTB} = a + b*FL_{SL}$.

Sex	CFL range	SFL range	a	b	r^2	*n*
Combined	154.0–272.0	150.0–264.7	3.335	0.9653	0.9937	35
Female	187.0–272.0	184.0–264.7				14
Male	154.0–269.4	150.0–262.5				21

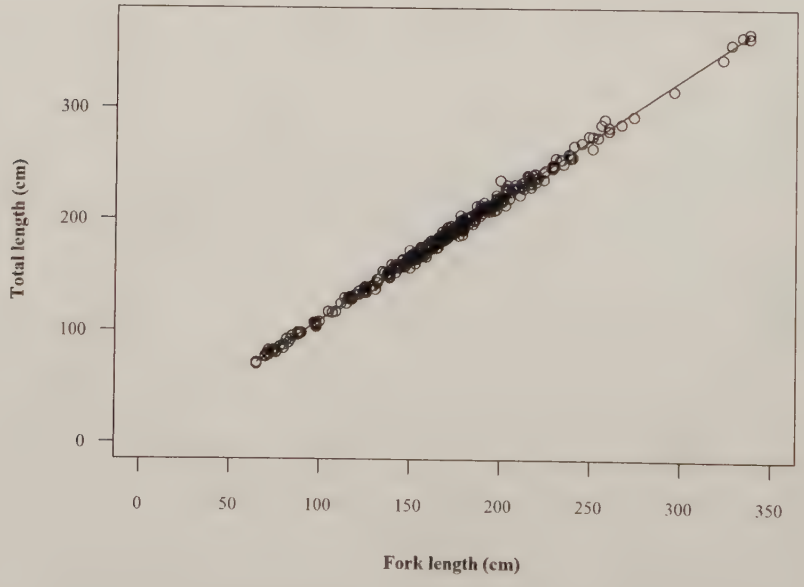


Figure 24A.–Relationship between over-the-body fork length and total length for shortfin makos from the western North Atlantic Ocean (sexes combined).

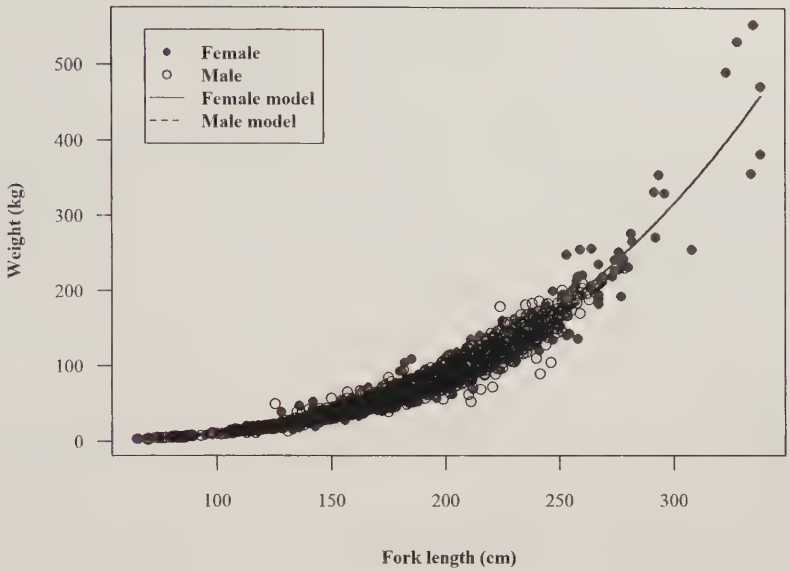


Figure 24B.–Relationship between over-the-body fork length and total weight for shortfin makos from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

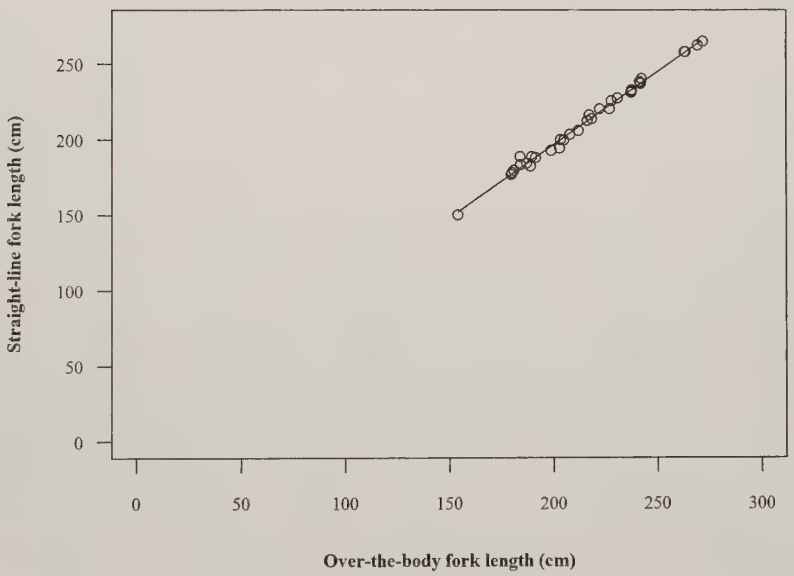


Figure 24C.–Relationship between over-the-body fork length and straight-line fork length for shortfin makos from the western North Atlantic Ocean (sexes combined).

Silky Shark, *Carcharhinus falciformis*

Table 25A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for silky sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	46.0–212.0	57.5–258.0	2.53	1.19	0.992	273
Female	49.7–212.0	66.0–258.0				144
Male	46.0–209.0	57.5–258.0				126

Table 25B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for silky sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	49.7–200.0	68.4–246.4	2.45	1.23	0.994	119
Female	49.7–200.0	68.4–246.4				66
Male	60.0–192.2	76.8–243.0				49

Table 25C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for silky sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	49.7–200.0	45.0–180.3	0.214	0.910	0.999	103
Female	49.7–200.0	45.0–180.3				58
Male	60.0–192.2	54.3–175.0				44

Table 25D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for silky sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	46.0–212.0	1.0–88.4	1.76E-05	2.90	2.73	358
Female	57.7–212.0	1.75–88.4	2.29E-05	2.85	3.19	198
Male	46.0–196.0	1.0–87.5	1.04E-05	3.01	1.94	157

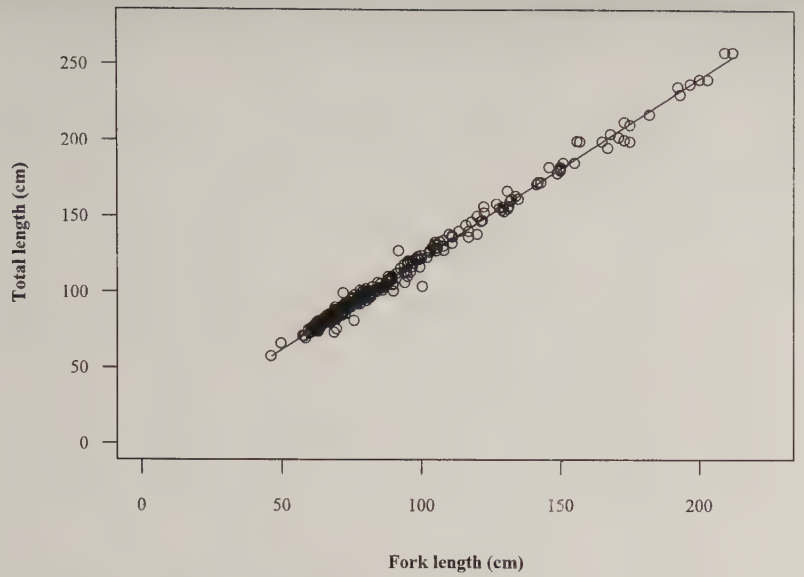


Figure 25A.–Relationship between over-the-body fork length and total length for silky sharks from the western North Atlantic Ocean (sexes combined).

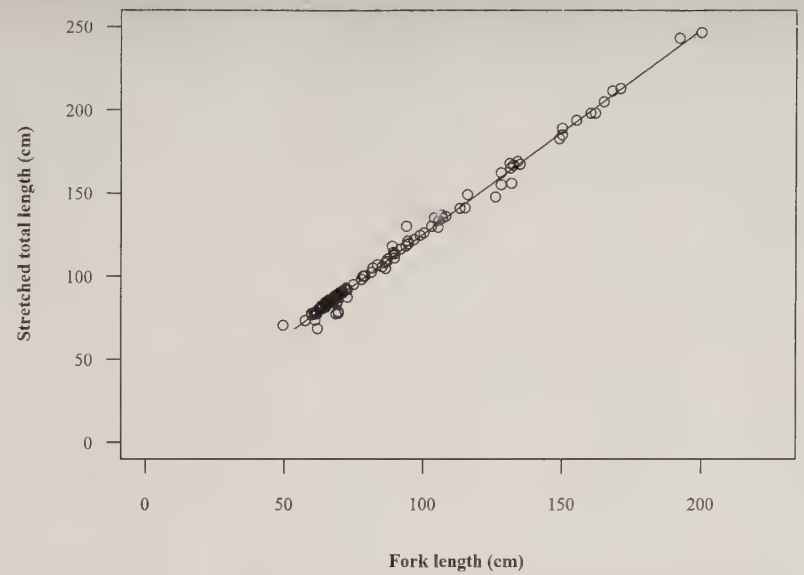


Figure 25B.–Relationship between over-the-body fork length and stretched total length for silky sharks from the western North Atlantic Ocean (sexes combined).

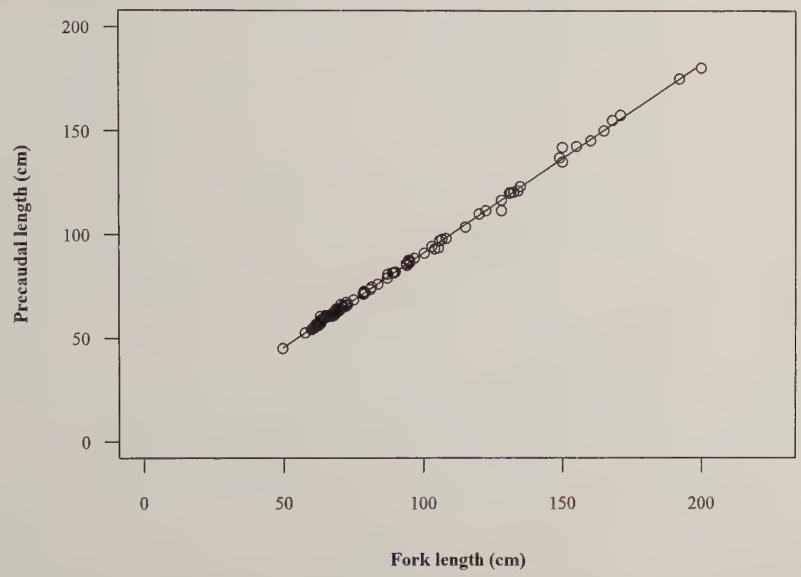


Figure 25C.–Relationship between over-the-body fork length and precaudal length for silky sharks from the western North Atlantic Ocean (sexes combined).

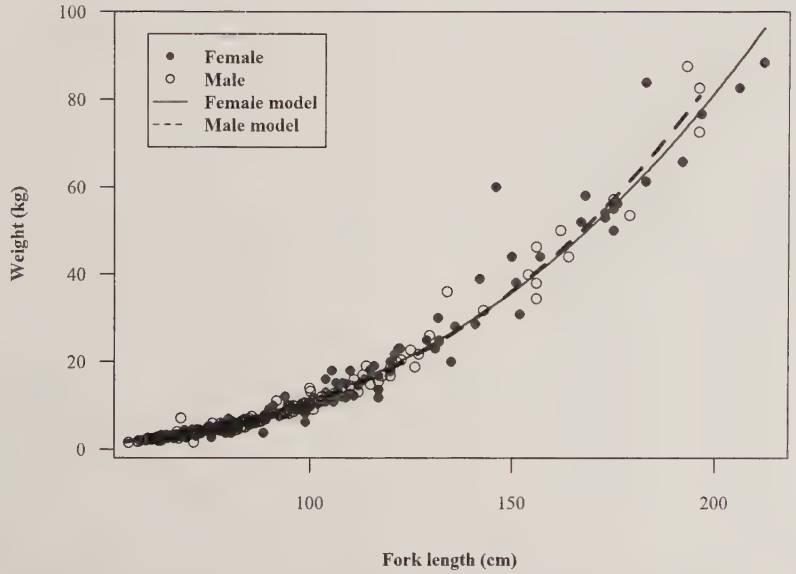


Figure 25D.–Relationship between over-the-body fork length and total weight for silky sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Smooth Dogfish, *Mustelus canis*

Table 26A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for smooth dogfish from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	26.0–122.0	29.0–134.0	2.10	1.10	0.996	1,746
Female	26.0–122.0	29.0–134.0				1,307
Male	26.0–104.5	30.0–116.0				431

Table 26B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for smooth dogfish from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	31.0–118.6	35.8–133.2	2.92	1.12	0.989	1,102
Female	32.0–118.6	37.0–133.2				999
Male	31.0–95.0	35.8–113.0				98

Table 26C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for smooth dogfish from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	31.0–122.8	28.1–105.0	-0.308	0.928	0.997	461
Female	32.0–112.8	29.0–105.0				376
Male	31.0–104.5	28.1–97.0				83

Table 26D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for smooth dogfish from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	29.0–118.0	0.05–9.0	3.67E-05	3.09	0.541	1,449
Female	29.0–118.0	0.01–9.0	1.10E-05	2.86	0.564	1,094
Male	30.0–104.5	0.05–6.5	6.69E-06	2.92	0.256	353

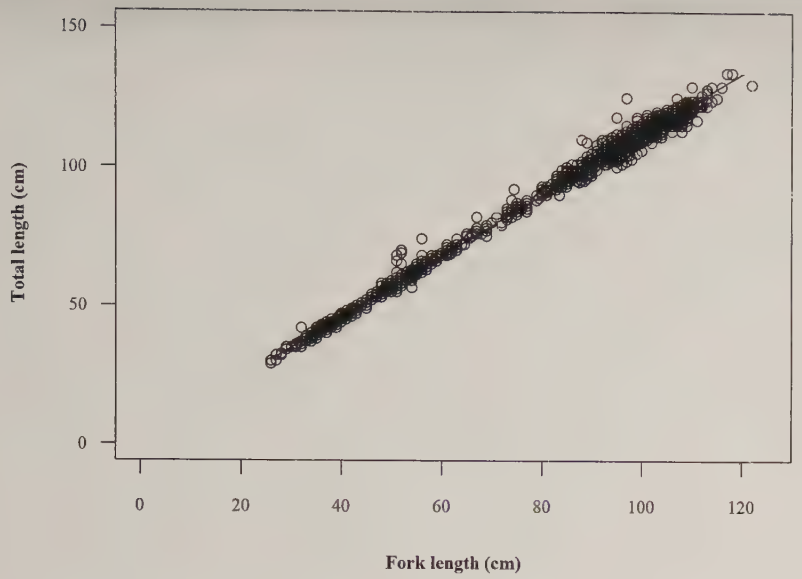


Figure 26A.–Relationship between over-the-body fork length and total length for smooth dogfish from the western North Atlantic Ocean (sexes combined).

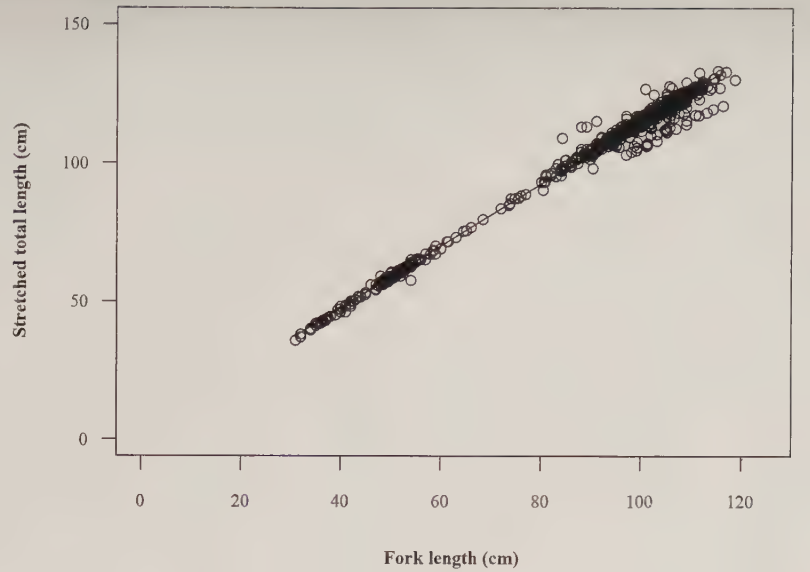


Figure 26B.–Relationship between over-the-body fork length and stretched total length for smooth dogfish from the western North Atlantic Ocean (sexes combined).

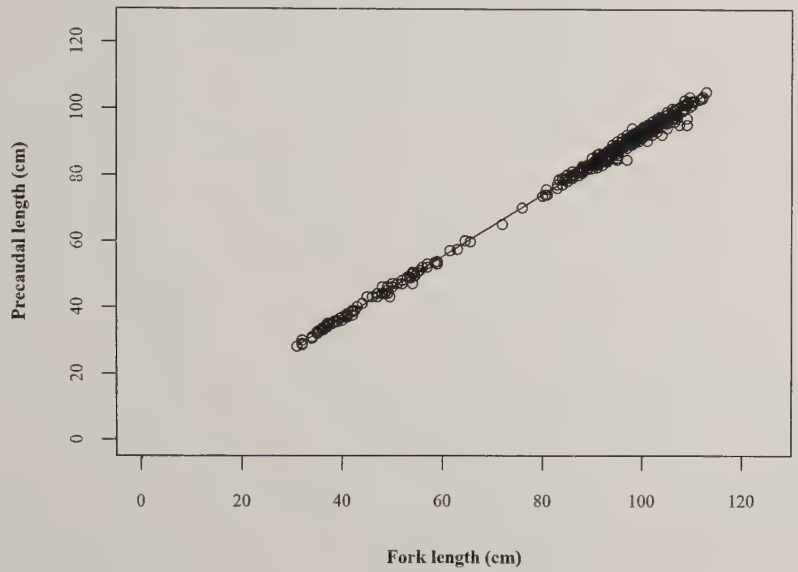


Figure 26C.–Relationship between over-the-body fork length and precaudal length for smooth dogfish from the western North Atlantic Ocean (sexes combined).

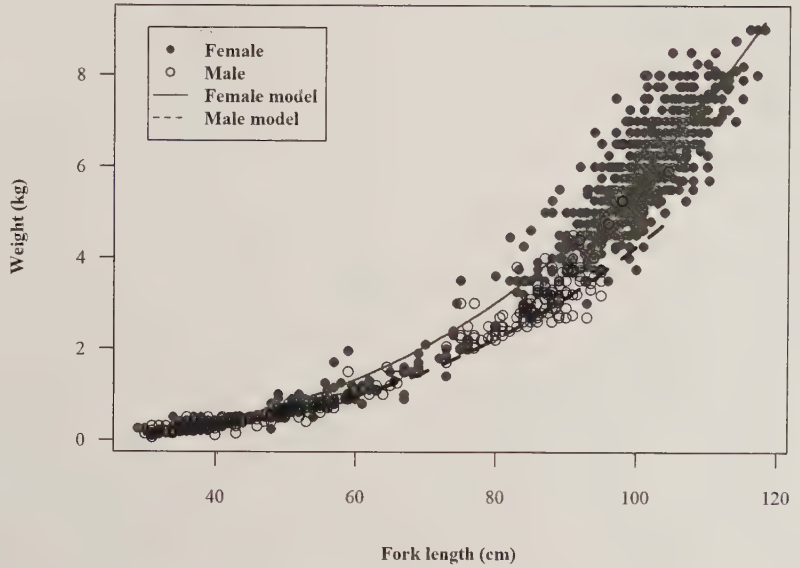


Figure 26D.–Relationship between over-the-body fork length and total weight for smooth dogfish from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Smooth Hammerhead, *Sphyrna zygaena*

Table 27A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for smooth hammerheads from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	40.0–234.0	51.0–292.0	0.925	1.24	0.996	13
Female	105.0–234.0	132.0–292.0				7
Male	40.0–169.0	51.0–208.0				6

Table 27B.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for smooth hammerheads from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	45.0–240.0	0.91–127.9	1.35E-05	2.90	12.7	34
Female	105.0–234.0	9.5–127.9	1.06E-06	3.41	6.76	22
Male	45.0–187.0	0.91–48.5	9.57E-06	2.97	3.83	10

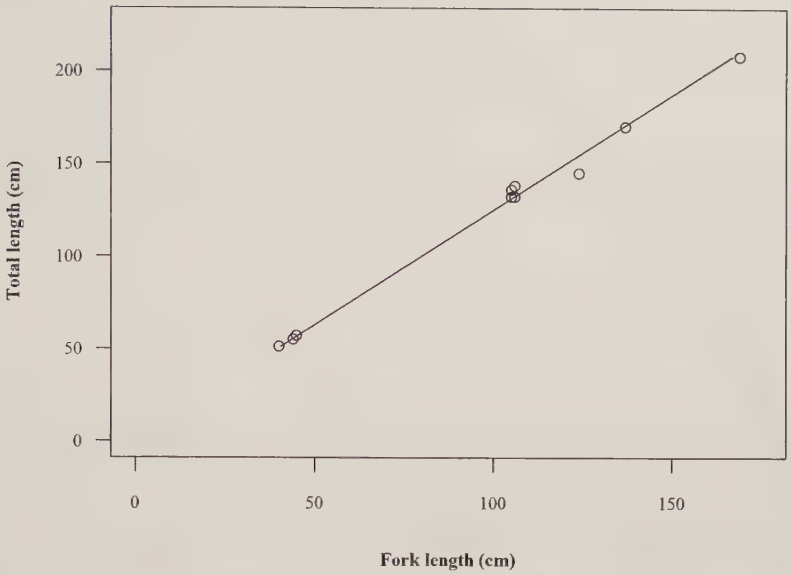


Figure 27A.–Relationship between over-the-body fork length and total length for smooth hammerheads from the western North Atlantic Ocean (sexes combined).

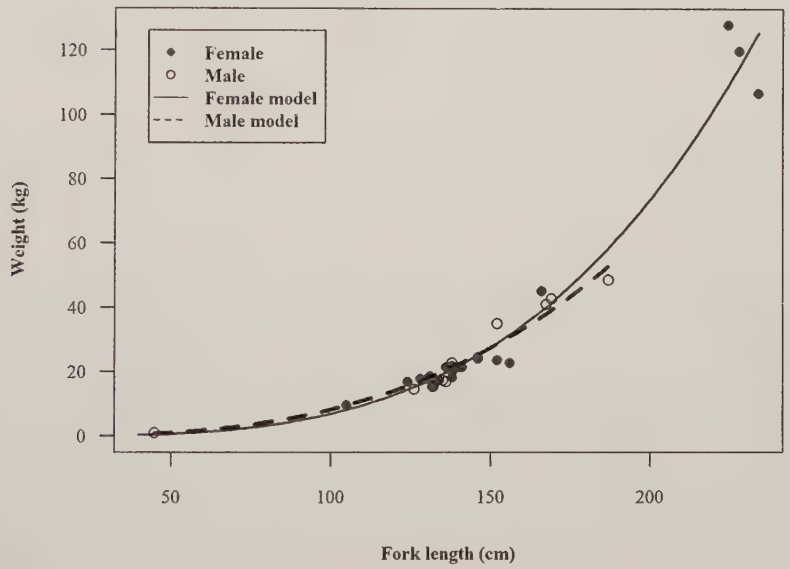


Figure 27B.–Relationship between over-the-body fork length and total weight for smooth hammerheads from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Spinner Shark, *Carcharhinus brevipinna*

Table 28A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for spinner sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	53.0–200.6	63.5–234.7	4.15	1.16	0.980	786
Female	53.0–200.6	64.0–234.7				411
Male	54.0–173.7	63.5–206.0				372

Table 28B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for spinner sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	50.4–188.0	63.4–227.0	2.50	1.21	0.996	835
Female	51.7–188.0	64.9–227.0				401
Male	50.4–162.0	63.4–204.0				426

Table 28C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for spinner sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	50.4–188.0	45.2–172.0	0.272	0.906	0.999	390
Female	52.0–188.0	46.5–172.0				184
Male	50.4–162.0	45.2–145.0				207

Table 28D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for spinner sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	50.4–186.2	0.37–71.0	4.75E-06	3.17	1.90	952
Female	51.7–186.2	1.25–71.0	4.11E-06	3.20	1.97	481
Male	50.4–179.0	1.0–55.0	8.57E-06	3.04	1.71	462

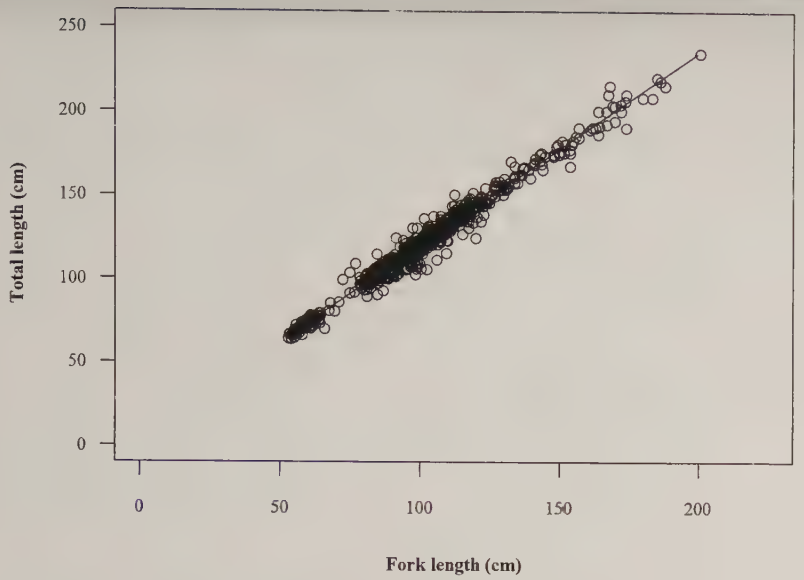


Figure 28A.–Relationship between over-the-body fork length and total length for spinner sharks from the western North Atlantic Ocean (sexes combined).

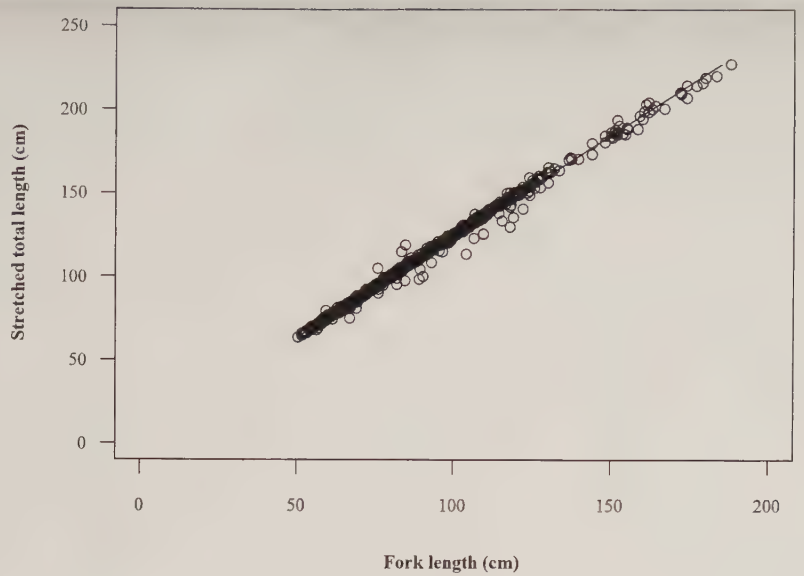


Figure 28B.–Relationship between over-the-body fork length and stretched total length for spinner sharks from the western North Atlantic Ocean (sexes combined).

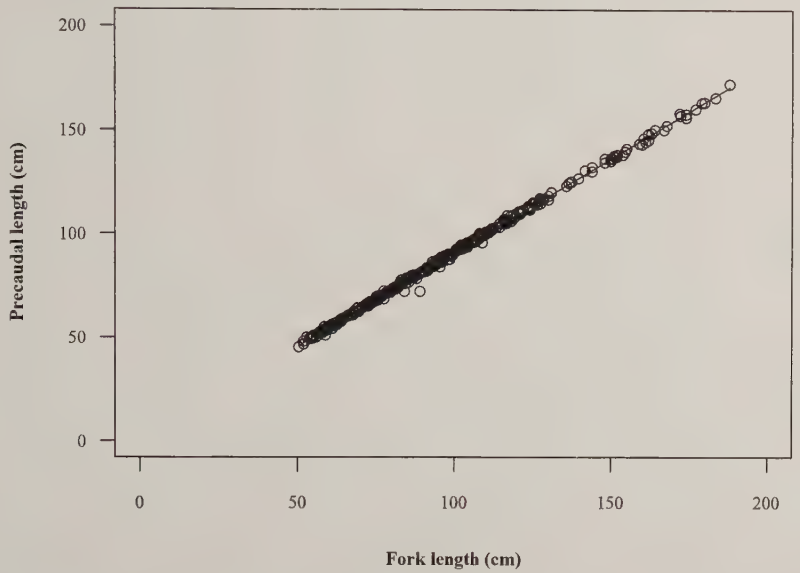


Figure 28C.–Relationship between over-the-body fork length and precaudal length for spinner sharks from the western North Atlantic Ocean (sexes combined).

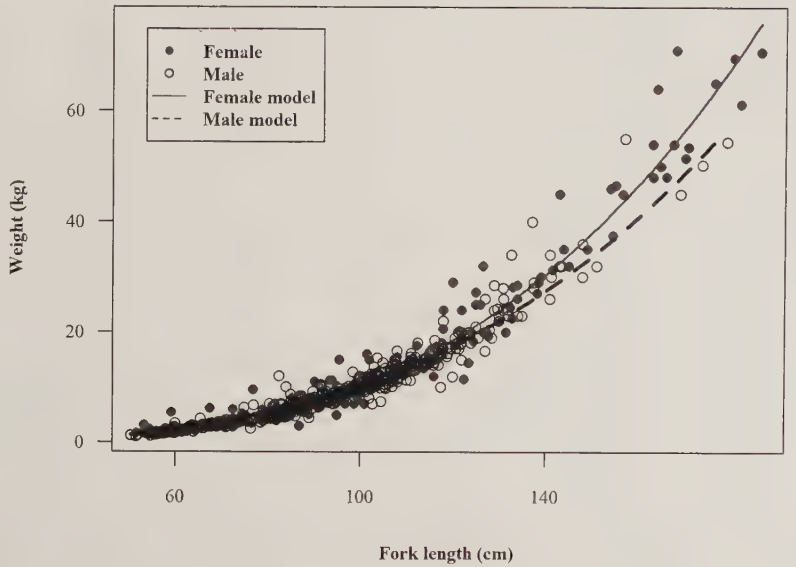


Figure 28D.–Relationship between over-the-body fork length and total weight for spinner sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Squalus spp.

Table 29A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for *Squalus* spp., from the Gulf of Mexico in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	31.5–86.5	35.0–97.0	0.019	1.12	0.993	86
Female	38.1–86.5	43.0–97.0				76
Male	31.5–81.0	35.0–91.0				10

Table 29B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for *Squalus* spp., from the Gulf of Mexico in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	35.0–68.8	40.0–75.4	3.59	1.06	0.987	45
Female	38.1–68.8	44.5–75.4				43
Male	35.0	40.0				2

Table 29C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for *Squalus* spp., from the Gulf of Mexico in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	31.5–68.8	28.5–62.3	-0.219	0.915	0.996	29
Female	38.1–68.8	35.1–62.3				26
Male	31.5–35.0	28.5–31.5				3

Table 29D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for *Squalus* spp., from the Gulf of Mexico in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	31.5–86.5	0.2–5.0	3.41E-06	3.19	0.227	110
Female	38.1–86.5	0.4–5.0	3.29E-06	3.20	0.227	99
Male	31.5–81	0.2–4.3	6.38E-06	3.05	0.236	11

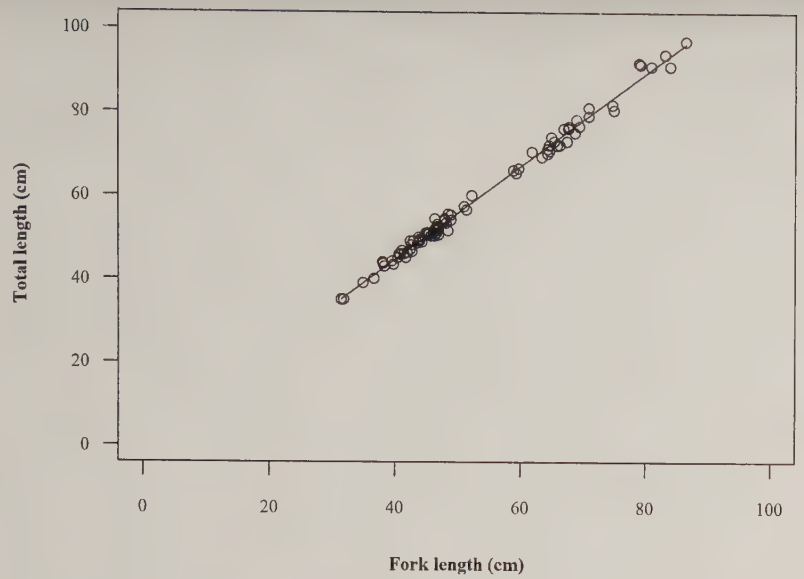


Figure 29A.–Relationship between over-the-body fork length and total length for *Squalus* spp., from the western North Atlantic Ocean (sexes combined).

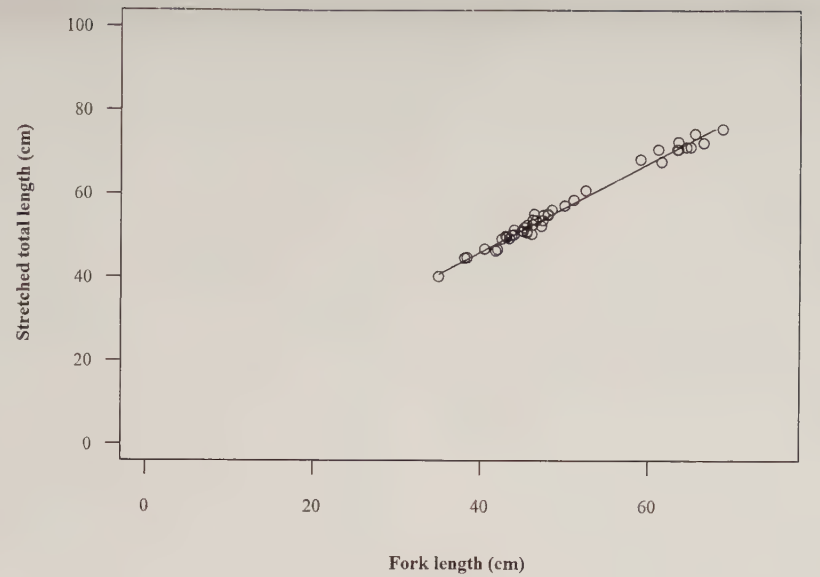


Figure 29B.–Relationship between over-the-body fork length and stretched total length for *Squalus* spp., from the western North Atlantic Ocean (sexes combined).

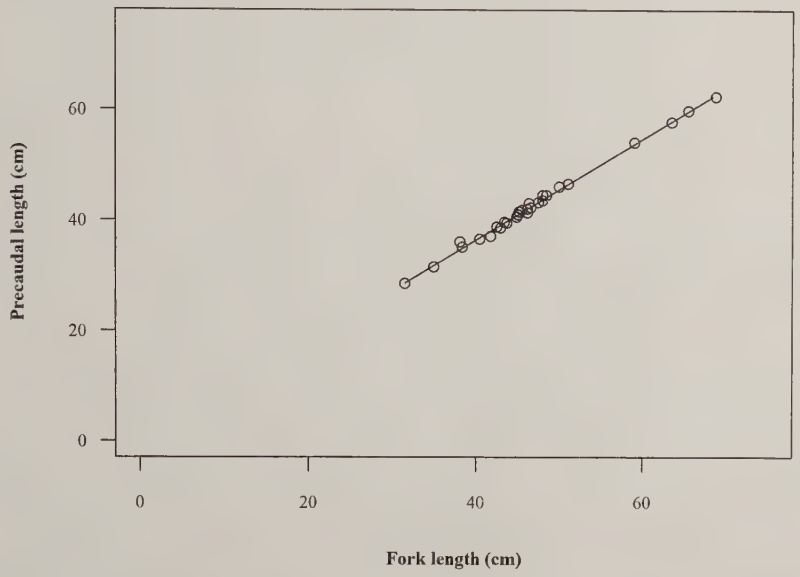


Figure 29C.–Relationship between over-the-body fork length and precaudal length for *Squalus* spp., from the western North Atlantic Ocean (sexes combined).

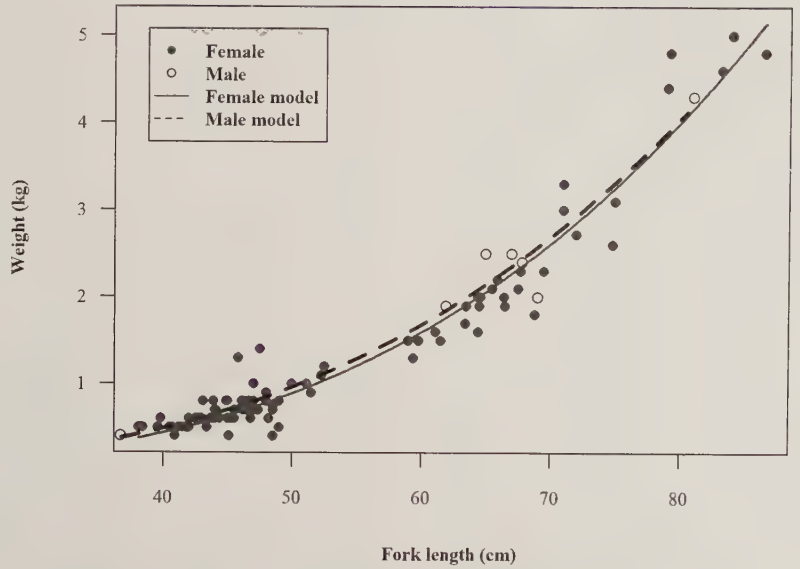


Figure 29D.–Relationship between over-the-body fork length and total weight for *Squalus* spp., from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Tiger Shark, *Galeocerdo cuvier*

Table 30A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for tiger sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	47.9–318.0	66.2–375.0	10.2	1.16	0.991	830
Female	47.9–318.0	66.5–375.0				411
Male	52.0–318.0	66.2–370.0				412

Table 30B.–Relationship between over-the-body fork length (FL_{OTB}) and stretched total length (TL_{STR}) for tiger sharks from the western North Atlantic Ocean in the form of $TL_{STR} = a + b*FL_{OTB}$.

Sex	FL range	TLS range	a	b	r^2	*n*
Combined	46.0–345.0	68.5–416.0	11.9	1.18	0.996	605
Female	51.5–345.0	72.0–416.0				331
Male	46.0–309.0	68.5–381.0				269

Table 30C.–Relationship between over-the-body fork length (FL_{OTB}) and precaudal length (PCL) for tiger sharks from the western North Atlantic Ocean in the form of $PCL = a + b*FL_{OTB}$.

Sex	FL range	PCL range	a	b	r^2	*n*
Combined	52.2–286.2	48.0–263.0	-0.863	0.911	0.999	339
Female	52.2–286.2	48.0–263.0				174
Male	56.3–280.0	50.0–258.0				164

Table 30D.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for tiger sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	46.0–349.0	0.2–540.2	3.04E-06	3.23	10.3	1,018
Female	47.9–349.0	0.2–540.2	1.97E-06	3.31	10.4	518
Male	46.0–318.0	0.5–348.4	4.98E-06	3.13	9.53	492

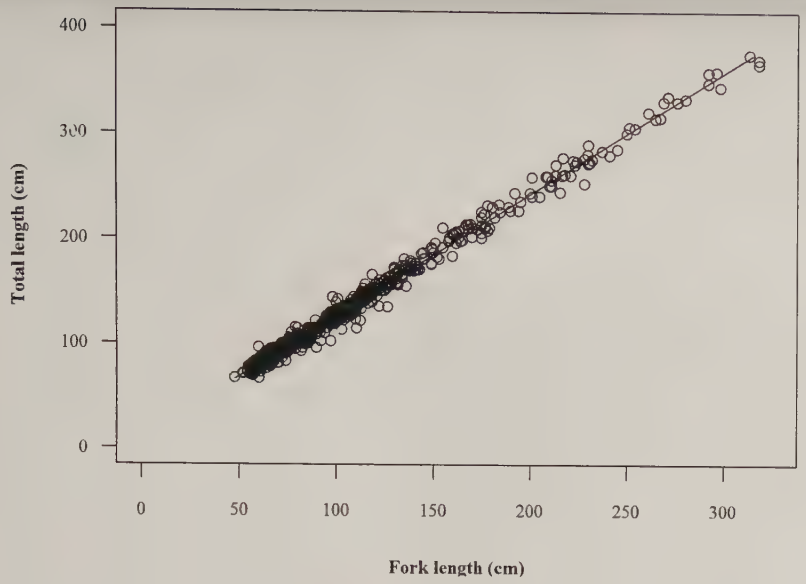


Figure 30A.–Relationship between over-the-body fork length and total length for tiger sharks from the western North Atlantic Ocean (sexes combined).

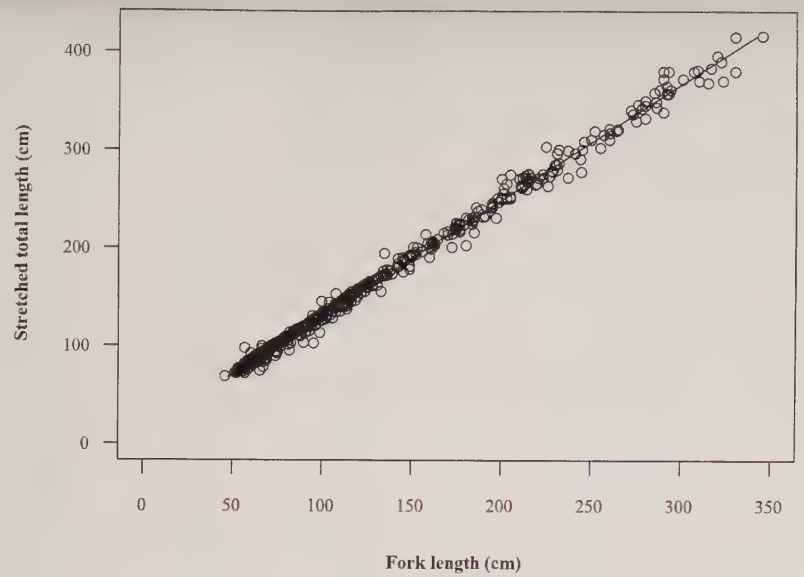


Figure 30B.–Relationship between over-the-body fork length and stretched total length for tiger sharks from the western North Atlantic Ocean (sexes combined).

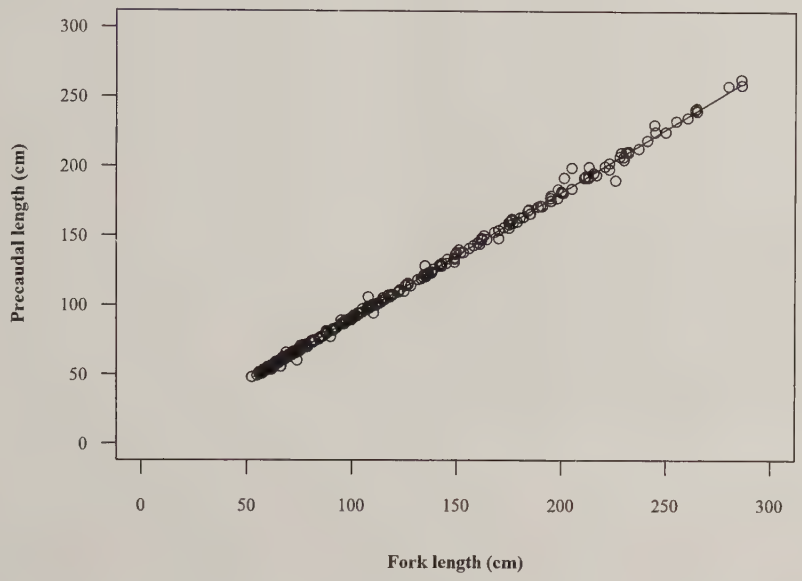


Figure 30C.–Relationship between over-the-body fork length and precaudal length for tiger sharks from the western North Atlantic Ocean (sexes combined).

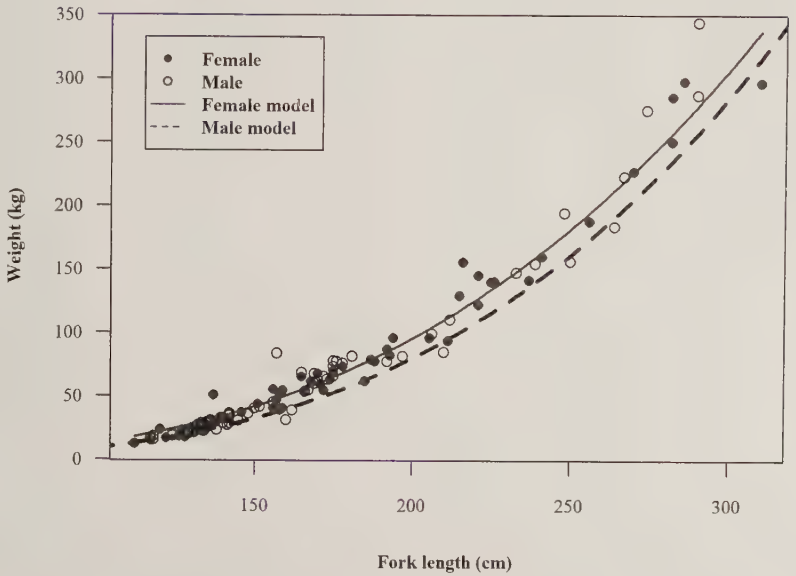


Figure 30D.–Relationship between over-the-body fork length and total weight for tiger sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

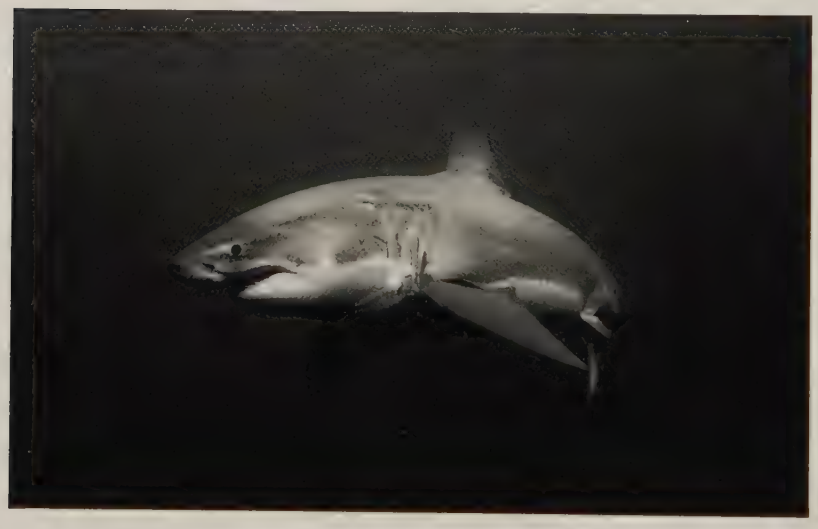
White Shark,
Carcharodon carcharias

Table 31A.–Relationship between over-the-body fork length (FL_{OTB}) and total length (TL_{OTB}) for white sharks from the western North Atlantic Ocean in the form of $TL_{OTB} = a + b*FL_{OTB}$.

Sex	FL range	TL range	a	b	r^2	*n*
Combined	112.0–493.0	122.0–517.0	5.86	1.06	0.995	126
Female	112.0–376.0	122.0–406.0				59
Male	117.0–493.0	130.0–517.0				65

Table 31B.–Relationship between over-the-body fork length (FL_{OTB}) and total weight (W) for white sharks from the western North Atlantic Ocean in the form of $W = aFL_{OTB}^{b}$.

Sex	FL range	Weight range	a	b	RSE	*n*
Combined	112.0–493.0	12.2–1,554.5	7.47E-06	3.09	38.2	141
Female	112.0–310.0	12.2–298.0	2.33E-05	2.87	11.0	68
Male	117.0–493.0	15.9–1,554.5	9.06E-06	3.06	52.7	71



White shark. Photo: Greg Skomal.

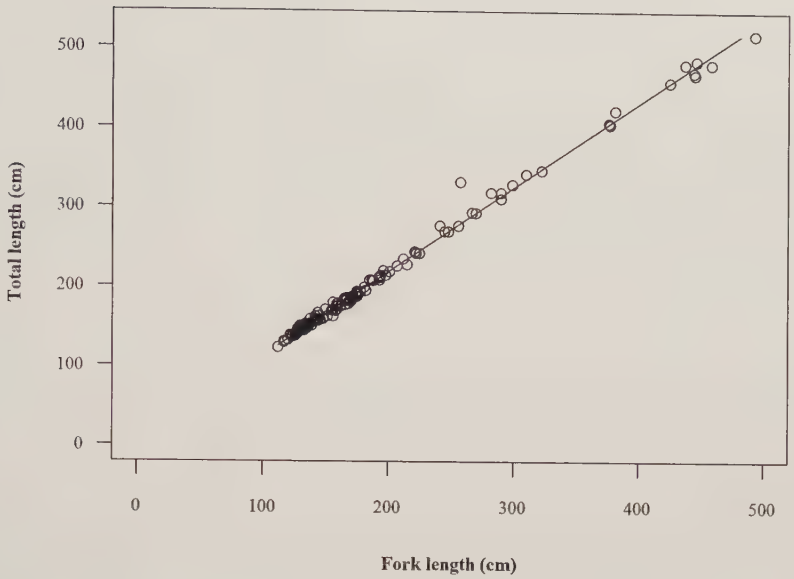


Figure 31A.–Relationship between over-the-body fork length and total length for white sharks from the western North Atlantic Ocean (sexes combined).

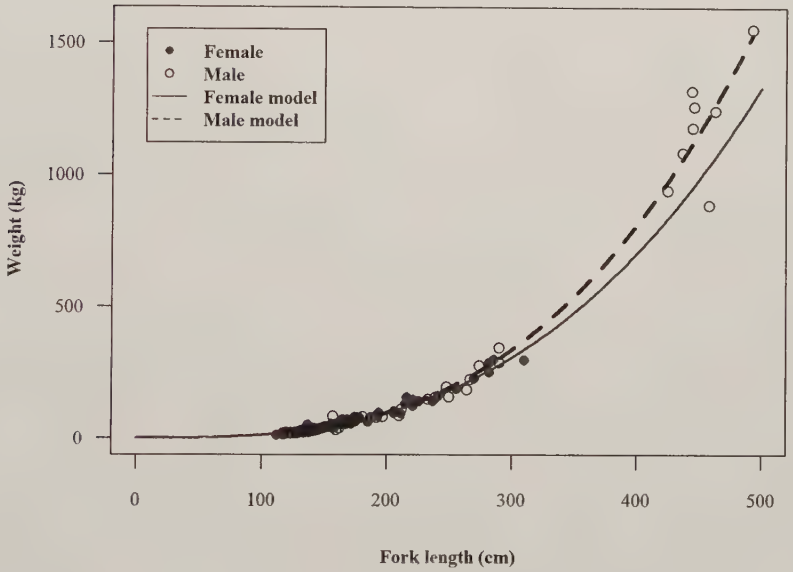


Figure 31B.–Relationship between over-the-body fork length and total weight for white sharks from the western North Atlantic Ocean. Solid circle = female, open circle = male, solid line = female, and dashed line = male.

Characterization of Protected Species Bycatch in the U.S. Gulf of Mexico and the Southeastern U.S. Atlantic Penaeid Otter Trawl, Rock Shrimp, and Skimmer Trawl Fisheries Based on Mandatory Observer Coverage from 2007 to 2019

JUDITH P. GOCKE, ELIZABETH SCOTT-DENTON, and JO ANNE WILLIAMS

*ABSTRACT—From 2007 to 2019, the southeastern U.S. shrimp fishery's mandatory observer program has collectively observed 1,766 U.S. Gulf of Mexico and southeastern U.S. Atlantic penaeid otter trawl, rock shrimp, and skimmer trawl trips. During observed shrimp trips, the program documented interactions with sea turtles, marine mammals, sawfish, giant manta rays, sturgeons, and seabirds. Spatial and temporal distribution of sea turtle interactions manifested higher numbers of mortalities off the coasts of Louisiana, Texas, and the southern waters of west Florida. Of the 280 sea turtles captured, 233 were alive at release. Marine mammal interactions, though low in number (*n *=16), resulted in near-total mortality. Habitat range of sawfish overlapped with fishery effort, resulting in captures (*n *=17) off Florida's coast with over 50% being released alive. Documentation of giant manta ray interactions began in 2019 and showed a higher occurrence in the southeastern U.S. Atlantic shrimp fishery relative to Gulf shrimp. The Gulf shrimp fishery off Louisiana and the southeastern U.S. Atlantic shrimp fishery off the coasts of the Carolinas and Georgia reported the capture of 14 sturgeons with close to 80% survival rate at release. Reporting of all captured seabird species was required; however, reports were low totaling 15.*

Introduction

Since its inception, a consequence of the commercial shrimp fishery has been the incidental capture of non-target species, referred to as bycatch. Fisheries bycatch is widely regarded as a wasted resource with adverse effects on stocks' productivity, discarded species, and disruptions to trophic webs and habitats at the ecosystem level (Crowder and Murawski, 1998; Harrington et al., 2005). The majority of shrimp species landed with commercial shrimp gear in the U.S. Gulf of Mexico and southeastern U.S. Atlantic are comprised of three species of penaeid shrimp, including brown shrimp, *Farfantepenaues aztecus*; white shrimp, *Litopenaeus setiferus*; and pink shrimp, *Farfantepenaeus duorarum*; and to a lesser degree, rock shrimp, *Sicyonia brevirostris*.

The capture, also referred to as interactions, of non-target species included the incidental take of threatened, endangered, and other marine protected species in commercial fishing gear. Captures or interactions are regulated by the National Marine Fisheries Service (NMFS), an agency of the National Oceanic and Atmospheric Administration (NOAA). NMFS management efforts include, but are not limited to, seasonal, temporal, and in-season area closures as well as gear modifications and restrictions. We will characterize interactions with sea turtles, marine mammals, sawfish, sturgeons, giant manta rays, and seabirds; emphasizing sea turtle interactions, documented by observers within the U.S. Gulf of Mexico and U.S. southeast Atlantic penaeid otter trawl, skimmer trawl, and rock shrimp fisheries.

Within these four fisheries, the NMFS Southeast Fisheries Science Center (SEFSC) observer program has documented interactions with the following sea turtle species: Kemp's ridley, *Lepidochelys kempii*; loggerhead, *Caretta caretta*; green, *Chelonia mydas*; hawksbill, *Eretmochelys imbricate*; and leatherback, *Dermochelys coriacea*. Captures of the following protected species are also documented: sawfish, *Pristis* spp.; smalltooth sawfish, *Pristis pectinate*; bottlenose dolphins, *Tursiops truncates*; unidentified marine mammals, Family Delphinidae; Atlantic sturgeon, *Acipenser oxyrinchus*; Gulf sturgeon, *Acipenser oxyrinchus desotoi*; giant manta ray, *Manta birostris*; and all seabirds.

The specific objectives of this paper are to 1) document interactions with protected species during commercial shrimp operations based on gear within the U.S. Gulf of Mexico and southeastern U.S. Atlantic penaeid otter trawl, skimmer trawl, and rock shrimp fisheries; and 2) quantify protected species interactions within the U.S. Gulf of Mexico and south U.S. Atlantic penaeid otter trawl, skimmer trawl, and rock shrimp fisheries by area and season using hot spot analyses to depict areas with significant clustering of high or low catch-per-unit-effort (CPUE) for sea turtles.

Background

In December of 1973 the Endangered Species Act (ESA) was passed in an effort to conserve protected species. The ESA was designed not only to prevent extinction but also to recover species. In the 1980's, a decline in finfish species of the U.S. Gulf of Mexico and southeastern U.S. Atlantic brought about federal management measures to determine the cause of the decline and develop ways to rebuild the affected stocks.

Concerns over bycatch in the 1990's prompted the Sustainable Fisheries Act

The authors are with the Southeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 4700 Avenue U, Galveston, TX 77551 (corresponding author: judy.gocke@noaa.gov).

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amendment to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA [16 USC 1801]). The SEFSC observer program, based in Galveston Texas, was provided authority to place observers on commercial fishing vessels operating within federally managed fisheries by MSFCMA, the Marine Mammal Protection Act (MMPA), and the ESA. These acts required the government to collect data and report on activities that affect marine resources. All data discussed here were collected by the above referenced observer program. The data collected by the observer program has, in turn, been used to provide data to promote fisheries management efforts to conserve and recover affected species.

In 1992, in response to the congressional mandates, the NMFS Southeast Fisheries Science Center, in cooperation with the Gulf and South Atlantic Fisheries Foundation, Inc. (Foundation), implemented a cooperative research plan to identify, develop, and evaluate gear options to reduce bycatch in the Gulf of Mexico and southeastern U.S. Atlantic shrimp fisheries (NMFS, 1991; Hoar et al., 1992). The goal was to evaluate bycatch species catch rates collected by shrimp trawlers and reduce finfish and protected species bycatch with the aid of bycatch reduction devices (BRD). Numerous BRD styles were developed by industry, scientists, and gear specialists and evaluated through cooperative multiyear efforts (NMFS, 1995; Scott-Denton and Nance, 1996; Branstetter, 1997; Nance and Scott-Denton, 1997; Nance et al., 1997; NMFS, 1998; Watson et al., 1999; Foster and Scott-Denton, 2004; NMFS, 2006; Scott-Denton, 2007; Helies and Jamison, 2009; Scott-Denton et al., 2012).

Through voluntary observer coverage, from 1992 to mid-July 2007, species-specific bycatch data from the U.S. Gulf of Mexico and southeastern U.S. Atlantic commercial shrimp fisheries were collected (Scott-Denton et al., 2007). The Texas Shrimp Association (TSA), North Carolina Division of Marine Fisheries (NCDMF), and the Georgia Department of Natural Resources (GDNR) have also collected observer data from commercial shrimp vessels and contributed to the shrimp trawl observer database. A voluntary component of the observer program continues for TED and BRD development and evaluation (Scott-Denton et al., 2012).

Joint voluntary observer coverage from 1992 to mid-July 2007 resulted in 158 observed trips with protected species interactions. Trips were designed to evaluate turtle excluder devices (TED's), naked nets (TED alternative-nets not equipped with TED's), BRD certifications, effort, and bycatch characterizations. NOAA observers completed 77 trips; 69 were observed by the Foundation, 6 by North Carolina Sea Grant, and 6 by the Georgia Department of Natural Resources. All combined, 525 sea turtles were captured (360 loggerheads, 115 Kemp's ridleys, 19 unidentified hardshell species, 18 greens, 9 leatherbacks, and 4 unknown species). In addition to sea turtles, voluntary observer coverage documented individual interactions with 7 marine mammals, 2 sturgeons, and 1 smalltooth sawfish.

To improve the statistical validity of data for the voluntary observer program, including bycatch, fishing effort, and fishery performance metrics, the Gulf of Mexico Fishery Management Council (GMFMC), through Amendment 13 to the Shrimp Fishery Management Plan (GMFMC, 2005), mandated observer coverage of federally permitted vessels; which required all vessels with federally regulated fishing permits to carry observers during fishing operation when selected by the observer program. Implementation of the mandatory observer program for the commercial shrimp fishery operating in the U.S. Gulf of Mexico began in 2007. Observer coverage was expanded in June 2008 to include the southeastern U.S. Atlantic penaeid and rock shrimp fisheries through Amendment 6 to the Shrimp Fishery Management Plan for the South Atlantic Region (SAFMC, 2005).

Increased interest in sea turtle mortality, within the SEFSC, prompted further expansion of the program, and NMFS observers were deployed off Louisiana's coast on inshore commercial skimmer vessels from 2004 to 2005. The skimmer trawl fishery is limited geographically; the nets are designed for fishing during shallow water, limiting the fleet's size to vessels with shallow drafts. Skimmer nets are pushed rather than pulled through the water, fished in nearshore surface waters, and not outfitted with turtle excluder devices (TED's). Fisheries observers provided coverage for a voluntary skimmer trawl fishery component (Scott-Denton et al., 2007); this was done through voluntary agreements with individual vessels. From 2004 to 2005, no protected species interactions were documented.

Further expansion occurred in 2008 and continued through 2010 to include coverage of North Carolina to evaluate TED's. In 2012, observer coverage of the skimmer trawl fishery off the coasts of Louisiana, Alabama, and Mississippi was made mandatory for vessels selected by the observer program. Voluntary coverage continued in addition to a mandatory component that began in May of 2012 (Pulver et al., 2012; 2014, Scott-Denton et al., 2014). From 2010 to 2015, the voluntary coverage resulted in 28 observed sea turtle interactions (16 Kemp's ridleys, 10 greens, and 2 loggerheads) and 12 seabird interactions.

Methods

Methods used in this investigation are those described by the current mandatory observer program operating in the U.S. Gulf of Mexico and along the southeastern U.S. Atlantic (Scott-Denton et al., 2012), as well as coastal Louisiana and North Carolina skimmer trawl observer programs (Scott-Denton et al., 2007). Observers were placed on otter trawl vessels from 2007 to 2019, targeting either penaeid or rock shrimp. Selections for placing observers on skimmer trawl vessels began in May 2012, targeting penaeid shrimp. The observer program operated in state and federal waters within the exclusive eco-

nomic zone (EEZ). The EEZ comprises an area that extends either from the coast or, in federal systems, from the seaward boundaries of state waters (3–12 n.mi., in most cases) to 200 n.mi. off the coast.

Vessels were selected to carry an observer from the current NMFS Southeast Regional Office (SERO) vessel permit lists (SERO, 2020). Skimmer trawl vessels were selected from state license holder lists. The number of vessels selected for each selection was dependent on funding availability, coverage needs, and varied based on the fishery and season. Selection letters were sent to owners of selected vessels via certified mail. Vessel owners were instructed to contact the observer program within 24 h upon receipt of the certified letter. Moreover, as a safety requirement, vessel operators were required to contact the United States Coast Guard (USCG) to obtain a current safety decal. The decal provided proof the vessel successfully passed a USCG dockside safety exam in compliance with the Commercial Fishing Industry Safety Act (Craig, 2014) prior to placing an observer onboard a vessel.

Shrimp vessels were selected based on the previous year's reported catch (landings/effort), stratified by area fished, water depth fished, and season. Similarly, the skimmer trawl fishery was stratified by area and season, with the assumption of depth as inshore or nearshore due to the nature of the fishery. Depth strata were classified as inshore (the area from the beach seaward inside the International Regulations for Preventing Collisions at Sea 1972 [72 COLREGS] line), nearshore (the water outside the inshore lines, ≤ 10 fm), and offshore (> 10 fm). Fishing areas were delineated by statistical zones (Patella, 1975; Fig. 1). The statistical zones were broken down into 34 areas: 1–9 west coast of Florida, 10–11 Alabama/Mississippi, 12–17 Louisiana, 18–21 Texas, 24–30 east coast of Florida, 31 Georgia, 32–33 South Carolina, and 34–36 North Carolina. Similarly, for the Atlantic, lat. 24°00'N–30°42.5'N denote the east coast of Florida, > lat. 30°42.5'N–32°00'N depict Georgia, > lat. 32°00'N–33°51.6'N represent South Carolina, and > lat. 33°51.6'N delineate North Carolina (Scott-Denton et al., 2012).

Seasons were fishery specific; the U.S. Gulf of Mexico and southeastern U.S. Atlantic penaeid otter trawl fisheries were broken down into three seasons per year (January–April, May–August, and September–December). The rock shrimp fishery was covered during one season (July–November), and inshore commercial shrimp skimmer trawl and North Carolina TED testing consisted of one season (May–August); if coverage and/or vessel compliance were not met and funding was available, seasonal coverage was extended (September–December).

Selected vessels were required to carry observers for a specific number of sea days, within the season for which they were selected, to satisfy permit obligations. A sea day was defined as any part of a day spent at sea, in transit, on anchor, or fishing without a return to port. The number of sea days a vessel was required to fulfill varied by fishery. The two fisheries that received the highest observer coverage, U.S. Gulf of Mexico and southeastern U.S. Atlantic penaeid otter trawl fisheries (Gulf shrimp and southeastern U.S. Atlantic shrimp), were required to carry an observer for 18 and 6 sea days, respectively, with fishery coverage year-round. Rock shrimp fishery required vessels to carry an observer for 11 sea days, and the skimmer trawl fishery required 5 sea days.

Fishing gear and biological sampling procedures were fisheries specific. Detailed descriptions for all sampling procedures can be found in the NMFS Characterization of the U.S. Gulf of Mexico and Southeastern Atlantic Otter Trawl and Bottom Reef Fish Fisheries Observer Training Manual (NMFS, 2020). Vessel information was recorded, including, but not limited to, the following: vessel length, hull material, gross tonnage, engine horsepower, and crew size. Net type and associated gear information (TED and BRD type) were recorded, as well as changes to gear throughout a trip. Tow specific information (beginning and end) included: date, time, Global Positioning System (GPS) coordinates, vessel speed, and water depth. Net information, per tow, included sample weight (kg), total catch weight (kg), total shrimp weight (kg), and status of BRD (open or closed). Sample weight was calculated by separating one basket from each sampled net (approximately 32 kg). Catch from the sample weight basket provided the species-specific information, collected per net, consisting of the scientific name, number of individuals, and sample or select weights (kg). Select weight referred to a particular species of commercial importance that was separated out of the total catch and was not included in the sample weight. No extrapolation was required for select species like red snapper, which were measured and counted separately.

Protected species interactions or captures were recorded as they occurred during both sampled and unsampled tows. Sampled tows were tows that occurred when the vessel was actively fishing with the main nets and the observer collected biological data. Unsampled tows were tows when the vessel was actively fishing and the observer was not collecting biological data. Sightings of protected species were recorded but not used in this analysis; sightings were not caught as bycatch and had no interaction with the vessel or gear. Protocols for the scientific sampling of protected species captured as bycatch followed the SEFSC permitted requirements and Observer Training Manual (NMFS, 2008; 2020). Data collected for sea turtles consisted of condition at the time of capture and release, injury status as a result of capture, biological information (measurements, scute counts and orientation, dorsal coloration), biological samples (skin tissue biopsies or carcass retention), gear interaction details, and tag application (flipper, passive integrated transponders [PIT] tags, and survival pop-up archival transmitting tags [sPAT]). Details of sea turtle interactions, includ-

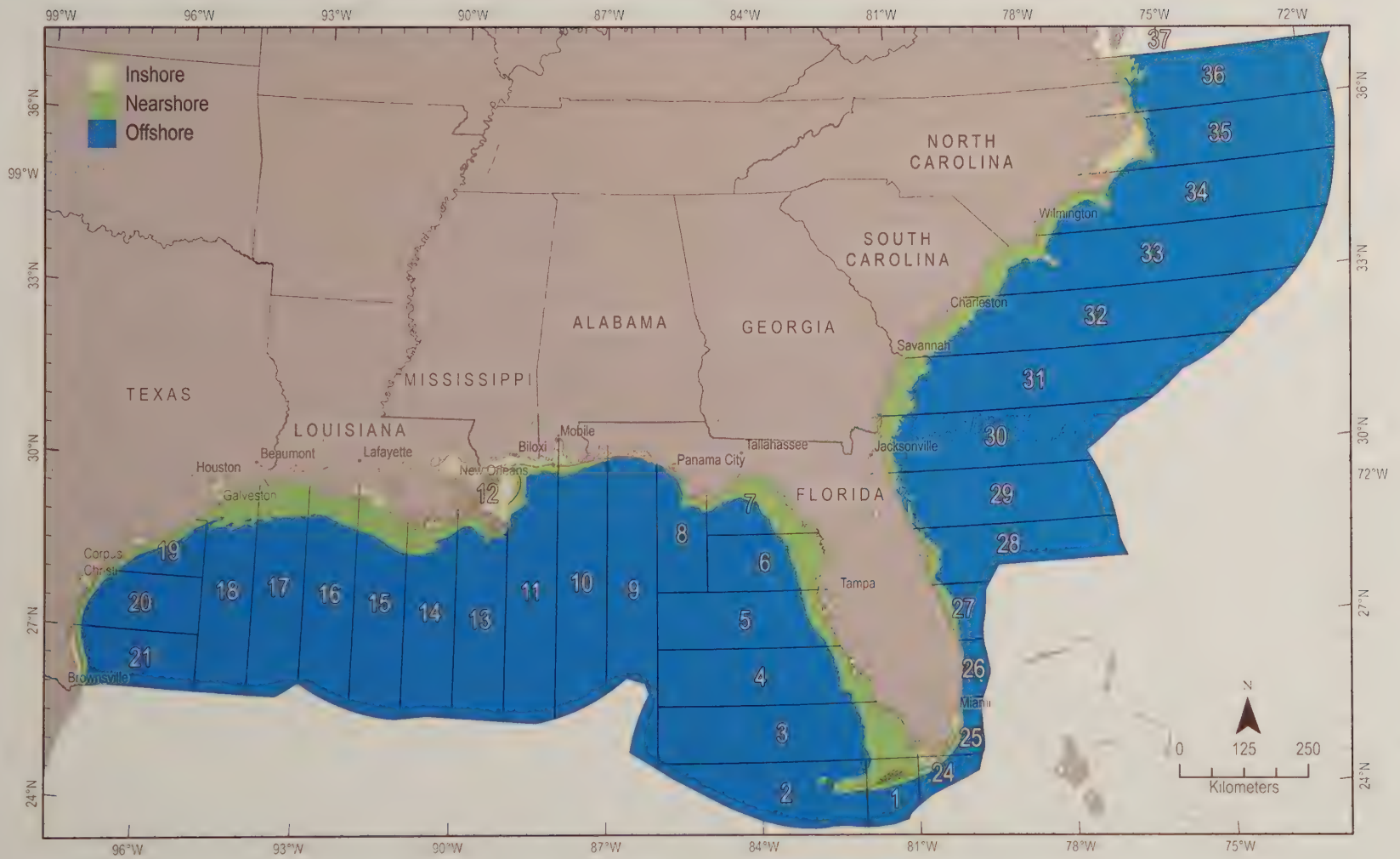

Figure 1.—Fishing area map delineated by statistical zones (Patella, 1975).

ing species and condition at the time of capture and release (i.e., alive, fresh dead/unresponsive, previously dead, unknown, or other), were reported to the SEFSC for scientific and management purposes, including annual sea turtle mortality assessments. Age and sex determinations were not made.

Marine mammal interactions were reported to the SEFSC; captures were categorized by species and condition of the marine mammal at the time of release (alive/swam away normally, alive/swam away abnormally, or dead). The Protected Resource Capture Report was completed for the capture of sawfish, sturgeon, giant manta ray, and seabirds and categorized by species and final disposition (alive, discarded dead/unresponsive carcass, or unknown) (Gocke, 2019). All interaction data was reported to the SEFSC generally within 24 h of capture.

Statistical Methods

All protected species results reported are non-extrapolated and based on the total number of interactions. Data for all interactions, regardless of operations problems (e.g., torn nets, hangs, clogging, and faulty gear), were included to represent standard commercial operations experienced by the fishery. If required, all nets used were consistent with current BRD regulations. Two to four nets were towed during standard fishing operation; effort metrics are based on the single net where protected species interaction occurred.

The surface density of fishing effort was created using the ArcGIS Pro Kernel Density[1] tool (Esri Inc, 2020). This tool calculated the density of feature values within a specified search radius around the feature and created a smooth surface of the magnitude per unit area. The search radius was based on the average minimum tow length plus the standard deviation for each fishery (20 km for Gulf and rock shrimp; 10 km for southeastern U.S. Atlantic shrimp; 5 km for skimmer trawl).

[1]Reference to trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

CPUE of sea turtle interactions were calculated using tow hours (calculated per tow hour based on a single net in which interaction occurred, regardless of the total number of nets towed). For try net interactions, try net tow times were used, if available. To identify statistically significant spatial clusters of high or low sea turtle CPUE, a local spatial statistic, the Getis-Ord Gi* (Gi*), was calculated using the Optimized Hot Spot Analysis tool in ArcGIS Pro. This tool analyzed the value (sea turtle CPUE) of each feature (tow location) in relation to the value of its neighboring features and compared each neighborhood to the value for all features within the dataset. Having a high value alone does not mean that a feature is a "hot spot" (or "cold spot" for low values)—it must be surrounded by features with similarly high (or low) values as well.

The tool used three strategies to determine the appropriate scale of analysis. The Incremental Spatial Autocorrelation tool was used to measure spatial autocorrelation at increasing distance increments. The distance associated with a statistically significant peak was used for the scale of analysis. This method was used for the Gulf shrimp fishery (peak clustering found at 6,720.07 m) and the skimmer fishery (peak clustering found at 4.583.73 m).

If no peak distance was found, the tool computed the average distance that would yield K neighbors for each feature (where $K = 0.05 * N$, the number of features in the dataset) and used it as the scale of analysis. If the average distance that would yield K neighbors exceeded one standard distance, then the third method was used and the scale of analysis was set to one standard distance. The K neighbor average distance method was used to determine the scale of analysis for the southeastern U.S. Atlantic shrimp fishery (optimal fixed distance band of 5,731.0 m was based on the average distance to 30 nearest neighbors) and the rock shrimp fishery (the optimal fixed distance band of 1,5237.0 m was based on the average distance to 25 nearest neighbors).

These values for the scale of analysis determined which features were analyzed together in order to assess local clustering. The local sum for a feature and its neighbors was compared proportionally to the sum of all features. The tool generated a z-score, p-value, and the number of neighbors for each feature. When the local sum was very different from the expected local sum, and when that difference was too large to be the result of random chance, a statistically significant z-score resulted.

For statistically significant positive z-scores, the larger the z-score was, the more intense the clustering of high values (hot spot). For statistically significant negative z-scores, the smaller the z-score was, the more intense the clustering of low values (cold spot). The p-value was a measure of probability. The lower the p-value, the more likely it was that the pattern of high or low values was a statistically significant cluster and was not due to random chance but rather the result of some underlying spatial process.

A False Discovery Rate (FDR) correction was applied to adjust the statistical significance to account for multiple testing and spatial dependency. Based on an FDR correction, the Gulf shrimp fishery had 1,302 tow locations with statistically significant high or low turtle CPUE's. The southeast U.S. Atlantic had 130; the rock shrimp fishery had no statistically significant clusters of high or low sea turtle CPUE values. The skimmer fishery had 384 tow locations with statistically significant clusters of high or low sea turtle CPUE values. To effectively visualize the hot spot analysis results, an inverse distance weighted technique (ArcGIS Pro IDW Spatial Analyst tool) was used to create a continuous surface.

Results

The mandatory shrimp trips observed, by the program, from July 2007 through December 2019 totaled 1,766 (Table 1). In July 2007, 100% of the observer program's coverage was concentrated in the Gulf shrimp

fishery. As the observer program progressed, fishing effort was distributed across four mandatory fisheries (Gulf shrimp, southeastern U.S. Atlantic shrimp, rock shrimp, and skimmer trawl); however, the highest concentration of effort remained in the Gulf shrimp fishery. Of the 1,766 trips completed, shrimp catch from 46,098 tows was sampled targeting penaeid and rock shrimp during 20,813 sea days of operation.

Observed Gulf shrimp fishery trips consisted of 38,186 tows (18,642 sea days), comprising 83% of the observed tows by year and fishery across all fisheries from 2007 to 2019 (Table 1). As fishing effort was distributed throughout the different fisheries, the Gulf shrimp fishery produced the highest sea days by year and fishery at 90%. When the years were combined and evaluated spatially, fishing effort spanned the entire U.S. Gulf of Mexico. The highest concentration of fishing effort was completed in statistical zones 11–17 off Louisiana and Mississippi's coasts. Statistical zone 21 off the coast of Texas and zone 2 off the west Florida coast also exhibited high concentrations of effort (Fig. 2). When broken down by season, the highest concentration of h fished (> 1.484 h fished/km^2) occurred from May through August off the coast of Louisiana in statistical zones 11–16 (Fig 3–5).

A total of 3,567 tows (1,411 sea days) were sampled in the southeastern U.S. Atlantic shrimp fishery resulting in 8% of the completed tows for the whole observer program encompassing the years 2007–19 (Table 1). Percent coverage by sea days in the southeastern U.S. Atlantic shrimp fishery did not exceed 12% during this period. The highest concentration of effort in the combined years was located in North Carolina (statistical zone 35); small pockets of fishing effort were also situated off the coast of eastern Florida and Georgia in zone 29–31 (Fig. 6). May through August produced the highest concentration of fishing effort off the coast of North Carolina in statistical zone 35 (>1.143 h fished/km^2) with slightly lower concentrations (> 0.417 h fished/km^2) off the coasts of South Carolina, Georgia, and eastern Florida in statistical zones 28–33. Effort was concentrated in the same locations during season three, September through December, with slightly lower effort (> 0.417 to ≤ 1.143 h fished/km^2) (Fig. 7–9).

The rock shrimp fishery off Florida's eastern coast consisted of 502 tows by year and fishery (226 sea days) totaling 1% of the overall tows sampled by the observer program during 2007–19 (Table 1). Percent coverage by sea days was at its highest point in 2008 at 3%. Florida's east coast received the highest concentration of effort in statistical zones 29–27 with maximum effort in zone 28. Effort occurred, to a lesser degree, in zones 7 and 8 off the coast of west Florida south of Apalachicola and in statistical zones 2–4 (Fig. 10). The highest concentration of effort occurred at the beginning of the season >0.211 h fished/km^2 (May–August) and continued at lower concentrations (>0.077 to ≤ 0.211 h fished/km^2) to the end of the season in November (Fig. 11–13).

Observed mandatory coverage of the skimmer trawl fishery, which began in 2012, completed 3,843 tows (534 sea days) off Louisiana, Missis-

Table 1.—Trips, tows, sea days, and percent distribution of observer coverage across projects by year and program, based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

Item	Year	Gulf penaeid otter trawl	South Atlantic penaeid otter trawl	Rock	Skimmer trawl	Total
Trips by year and fishery	2007	31 (100%)				31
	2008	107 (78%)	27 (20%)	3 (2%)		137
	2009	105 (60%)	68 (39%)	2 (1%)		175
	2010	104 (78%)	29 (22%)	1 (1%)		134
	2011	76 (55%)	59 (43%)	2 (1%)		137
	2012	80 (43%)	46 (25%)		58 (32%)	184
	2013	82 (47%)	54 (31%)	4 (2%)	35 (20%)	175
	2014	94 (73%)	16 (12%)	1 (1%)	18 (14%)	129
	2015	97 (66%)	24 (16%)	2 (1%)	23 (16%)	146
	2016	118 (66%)	45 (25%)	2 (1%)	15 (8%)	180
	2017	106 (80%)	18 (14%)	3 (2%)	5 (4%)	132
	2018	81 (69%)	24 (21%)	1 (1%)	11 (9%)	117
	2019	62 (70%)	19 (21%)	3 (3%)	5 (6%)	89
	Total	1,143 (65%)	429 (24%)	24 (1%)	170 (10%)	1,766
Tows by year and fishery	2007	1,242 (100%)				1,242
	2008	2,797 (90%)	202 (7%)	97 (3%)		3,096
	2009	2,918 (86%)	441 (13%)	16 (0%)		3,375
	2010	2,307 (93%)	145 (6%)	41 (2%)		2,493
	2011	2,677 (89%)	275 (9%)	50 (2%)		3,002
	2012	2,610 (70%)	370 (10%)		765 (20%)	3,745
	2013	3,357 (70%)	322 (7%)	70 (1%)	1,075 (22%)	4,824
	2014	3,570 (81%)	177 (4%)	24 (1%)	634 (14%)	4,405
	2015	3,297 (84%)	202 (5%)	40 (1%)	371 (9%)	3,910
	2016	3,749 (82%)	405 (9%)	43 (1%)	359 (8%)	4,556
	2017	4,282 (88%)	378 (8%)	77 (2%)	131 (3%)	4,868
	2018	3,306 (80%)	417 (10%)	6 (0%)	381 (9%)	4,110
	2019	2,074 (84%)	233 (9%)	38 (2%)	127 (5%)	2,472
	Total	38,186 (83%)	3,567 (8%)	502 (1%)	3,843 (8%)	46,098
Sea days by year and fishery	2007	639 (100%)				639
	2008	1,435 (91%)	86 (5%)	53 (3%)	(0%)	1,574
	2009	1,559 (88%)	206 (12%)	7 (0%)	(0%)	1,772
	2010	1,130 (93%)	68 (6%)	14 (1%)	(0%)	1,212
	2011	1,273 (91%)	102 (7%)	21 (2%)	(0%)	1,396
	2012	1,413 (85%)	140 (8%)		119 (7%)	1,672
	2013	1,588 (84%)	127 (7%)	30 (2%)	145 (8%)	1,890
	2014	1,731 (92%)	68 (4%)	9 (0%)	82 (4%)	1,890
	2015	1,555 (91%)	88 (5%)	19 (1%)	44 (3%)	1,706
	2016	1,869 (89%)	164 (8%)	18 (1%)	47 (2%)	2,098
	2017	1,840 (91%)	126 (6%)	34 (2%)	16 (1%)	2,016
	2018	1,580 (89%)	139 (8%)	1 (0%)	57 (3%)	1,777
	2019	1,030 (88%)	97 (8%)	20 (2%)	24 (2%)	1,171
	Total	18,642 (90%)	1,411 (7%)	226 (1%)	534 (3%)	20,813

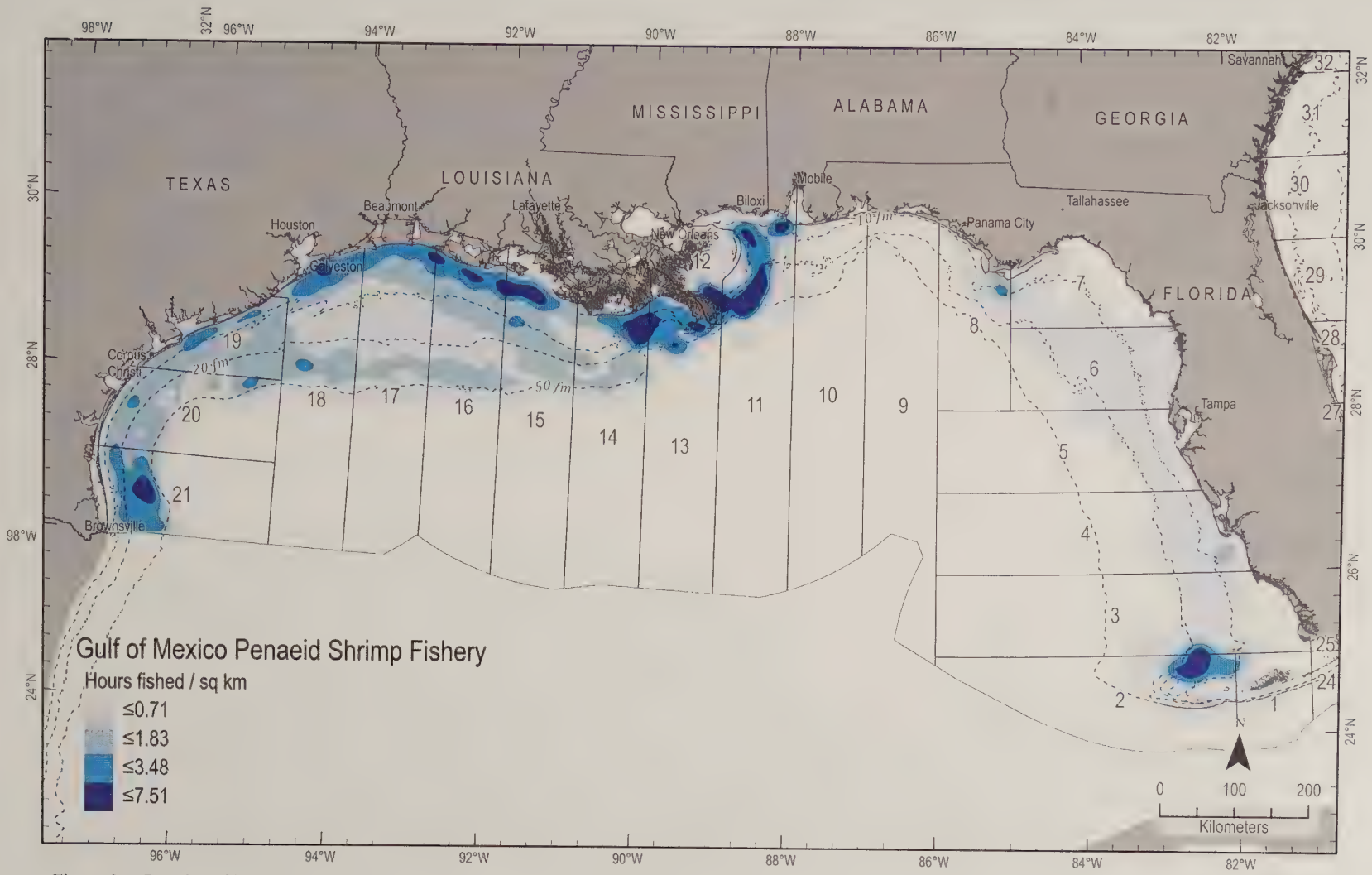

Figure 2.—Density of hours fished for the U.S. Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

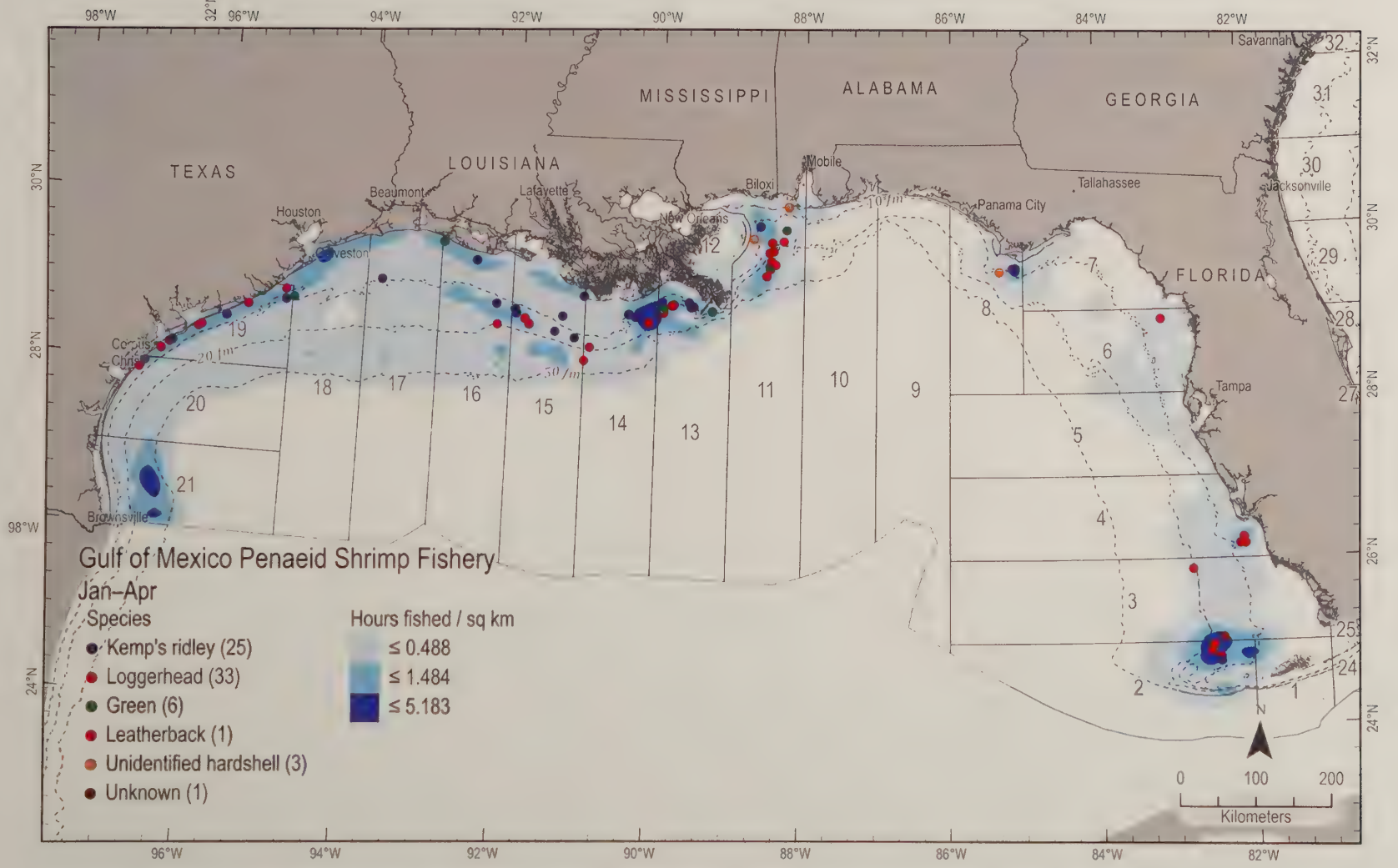

Figure 3.—Density of hours fished and sea turtle captures (n – 69), January through April, for the Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

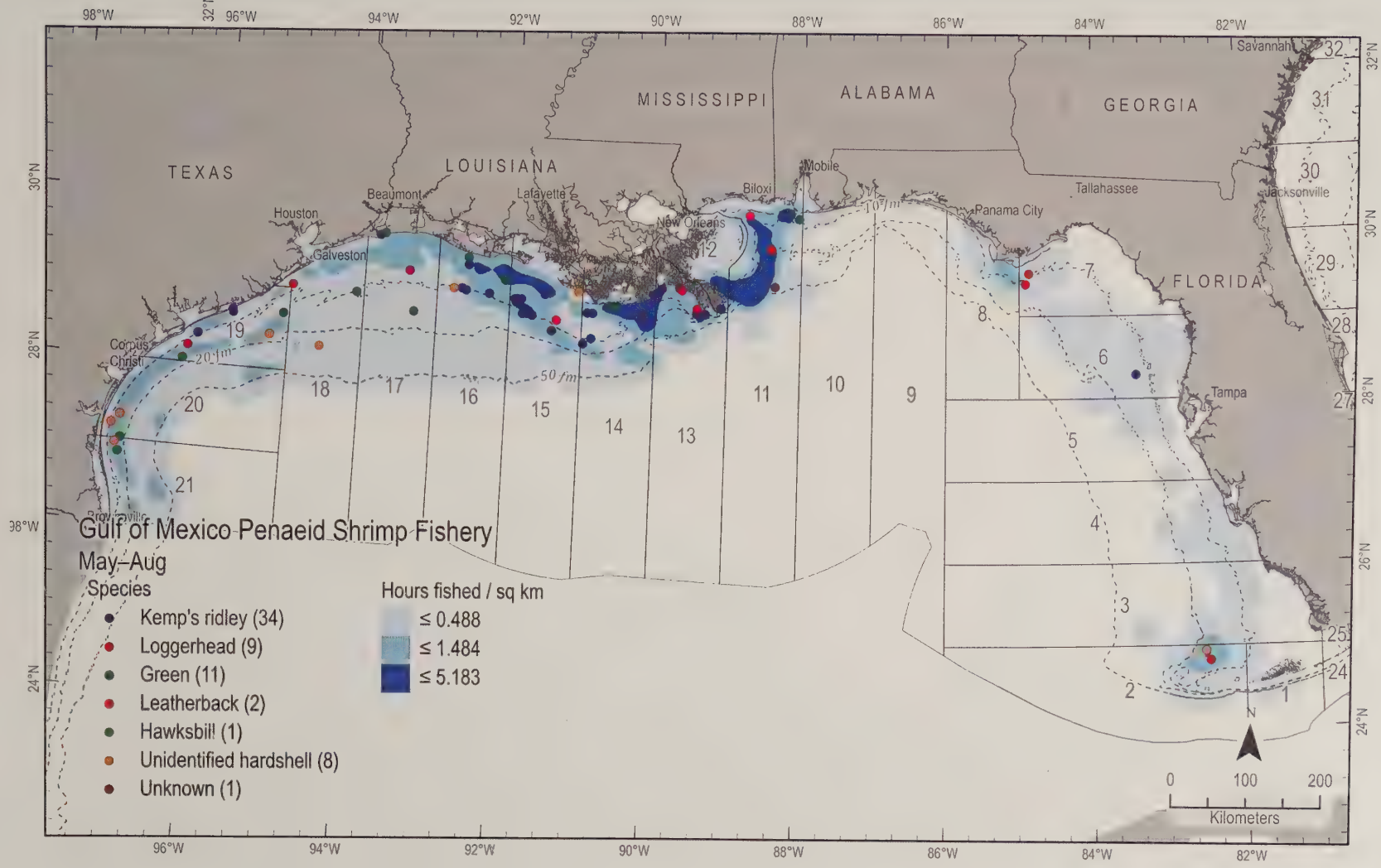

Figure 4.—Density of hours fished and sea turtle captures (n = 66), May through August, for the U.S. Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

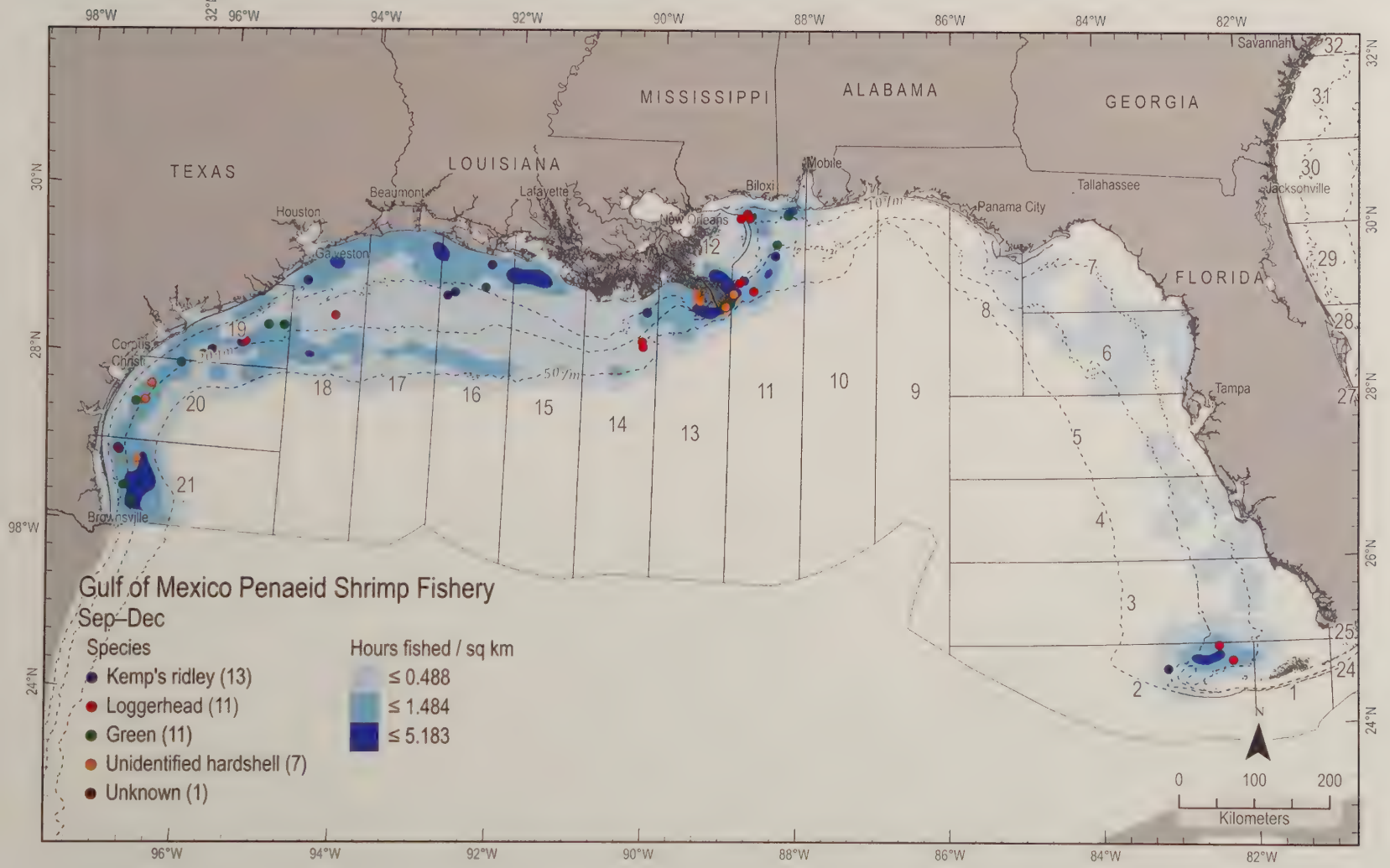

Figure 5.—Density of hours fished and sea turtle captures (n = 43), September through December, for the U.S. Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

sippi, and Alabama for 8% coverage of the total completed tows during 2007–19 (Table 1). Percent coverage by sea day was highest in 2013 at 8% and lowest in 2017 with 1% coverage. The largest concentration of effort was collected in the shallow water of Caillou Bay and Lake Pelto in statistical zone 14 with concentrations of effort near Marsh Island (statistical zones 15–16), in Black Bay (zone 12), and Barataria Bay (zone 13; Fig. 14). The skimmer trawl fishery generally began in May and was broken down into two seasons. The highest concentration of effort >1.709 h fished/km^2 occurred in May through August and tapered off during September through December with effort peaking at ≤1.709 h fished/km^2 (Fig. 15–17).

Protected Species Observations During Mandatory Observer Coverage

Turtle Characterization

From July 2007 through December 2019, 280 sea turtle captures were documented. Species and quantities of each varied over time with the following species recorded: Kemp's ridley, loggerhead, green, unidentified hardshell, leatherback, unknown/unidentified, and hawksbill (Table 2). The majority (n = 178) of the captures, occurred in the Gulf shrimp fishery. The second-highest concentration occurred in the skimmer trawl fishery with 58 captures. This was followed by the southeastern U.S. Atlantic fishery with a total of 39. The fewest number of captures occurred in the rock shrimp fishery, with a total of 5 loggerheads.

Tagging of captured turtles relied on the vessels' ability to board the turtle, size of the turtle, observer being given access to work up the turtle, and the availability of supplies while at sea. During mandatory coverage, 141 sea turtles were flipper tagged within the four fisheries, and 160 turtles were PIT tagged. Discrepancies between number of flipper and PIT tag application was predominantly due to collection regulations, as sea turtles must be of adequate size to safely flipper or PIT tag. Turtles greater than 30 cm straight carapace length (SCL) can be PIT and flipper tagged (NMFS, 2009). In cooperation with the SEFSC, Miami sea turtle researchers, sPAT tags were applied to 3 Kemp's ridleys and 3 loggerheads to augment a post-interaction mortality study. When boarded, every attempt was made by observers to collect biological information, biopsy samples, and apply tags (flipper, PIT, and sPAT tags).

Gulf Shrimp Fishery The largest numbers of turtles were captured between January and April (season 1), followed by May–August (season 2), with lowest concentration of captures in September–December (the final, sea-

Table 2.—Sea turtle capture and release status based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

Species Capture condition Disposition	Fishery				
	Gulf penaeid otter trawl	South Atlantic penaeid otter trawl	Rock	Skimmer trawl	Total
Kemp's ridley	72	11		48	131
Alive	45	11		43	99
Released alive	45	11		43	99
Fresh dead/unresponsive	26			4	30
Released alive	14			3	17
Salvaged carcass	3				3
Discarded carcass	9			1	10
Previously dead	1			1	2
Discarded carcass	1			1	2
Loggerhead	53	21	5	4	83
Alive	50	21	5	4	80
Released alive	49	21	5	4	79
Unknown	1				1
Fresh dead/unresponsive	2				2
Released alive	1				1
Discarded carcass	1				1
Previously dead	1				1
Discarded carcass	1				1
Green	28	2		4	34
Alive	10	2		1	13
Released alive	10	2		1	13
Fresh dead/unresponsive	18			2	20
Released alive	2				2
Salvaged carcass	6				6
Discarded carcass	9			2	11
Unknown	1				1
Previously dead				1	1
Discarded carcass				1	1
Unidentified hardshell	18	5		2	25
Alive	11	4		2	17
Released alive	11	4		2	17
Fresh dead/unresponsive	4				4
Discarded carcass	3				3
Unknown	1				1
Unknown	3	1			4
Unknown	3	1			4
Leatherback	3				3
Alive	2				2
Released alive	2				2
Fresh dead/unresponsive	1				1
Discarded carcass	1				1
Hawksbill	1				1
Alive	1				1
Released alive	1				1
Unknown	3				3
Unknown	3				3
Released alive	2				2
Unknown	1				1
Total	178	39	5	58	280

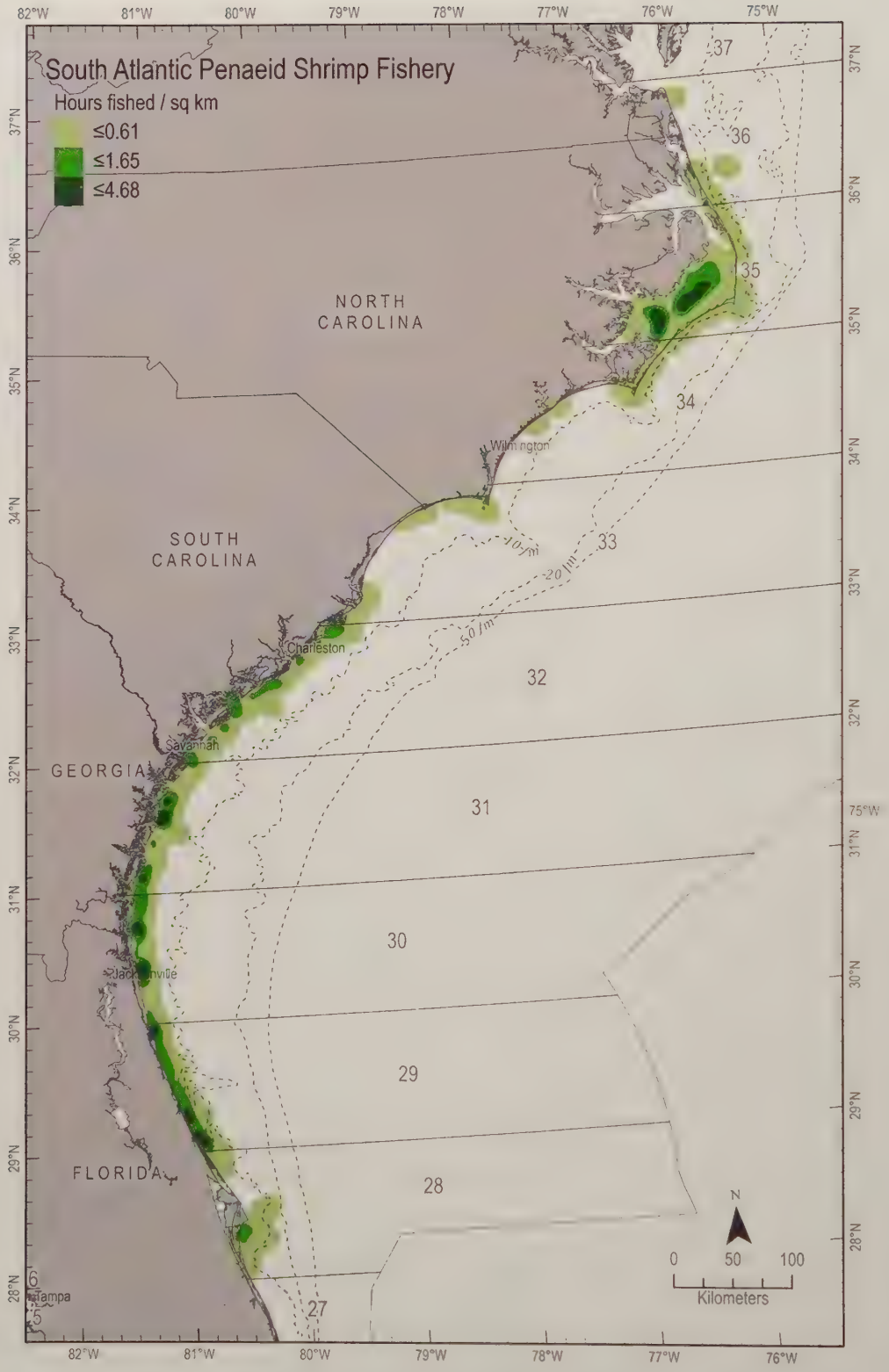

Figure 6.—Density of hours fished for the U.S. south Atlantic penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

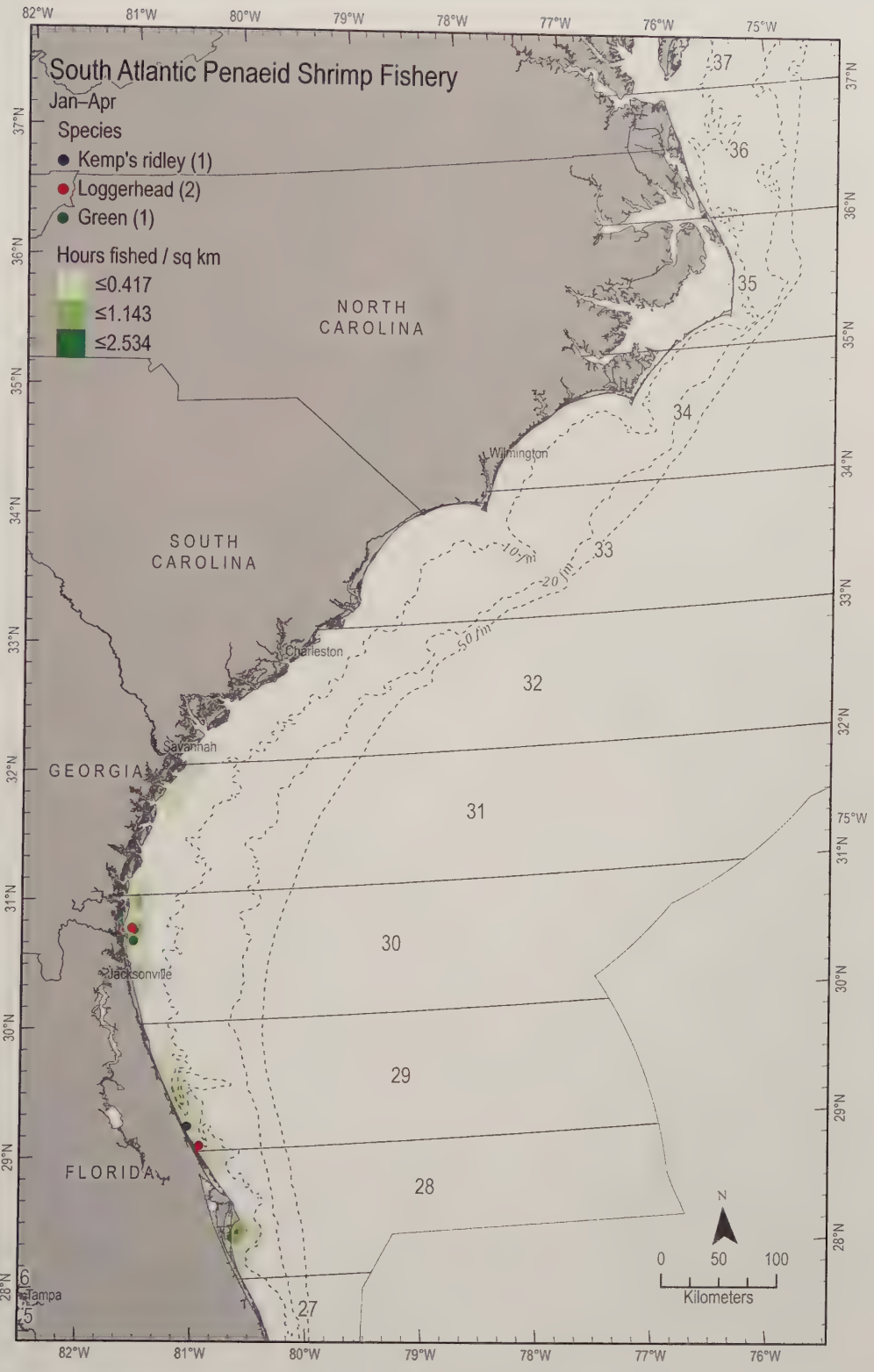

Figure 7.—Density of hours fished and sea turtle captures ($n = 4$), January through April, for the U.S. south Atlantic penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

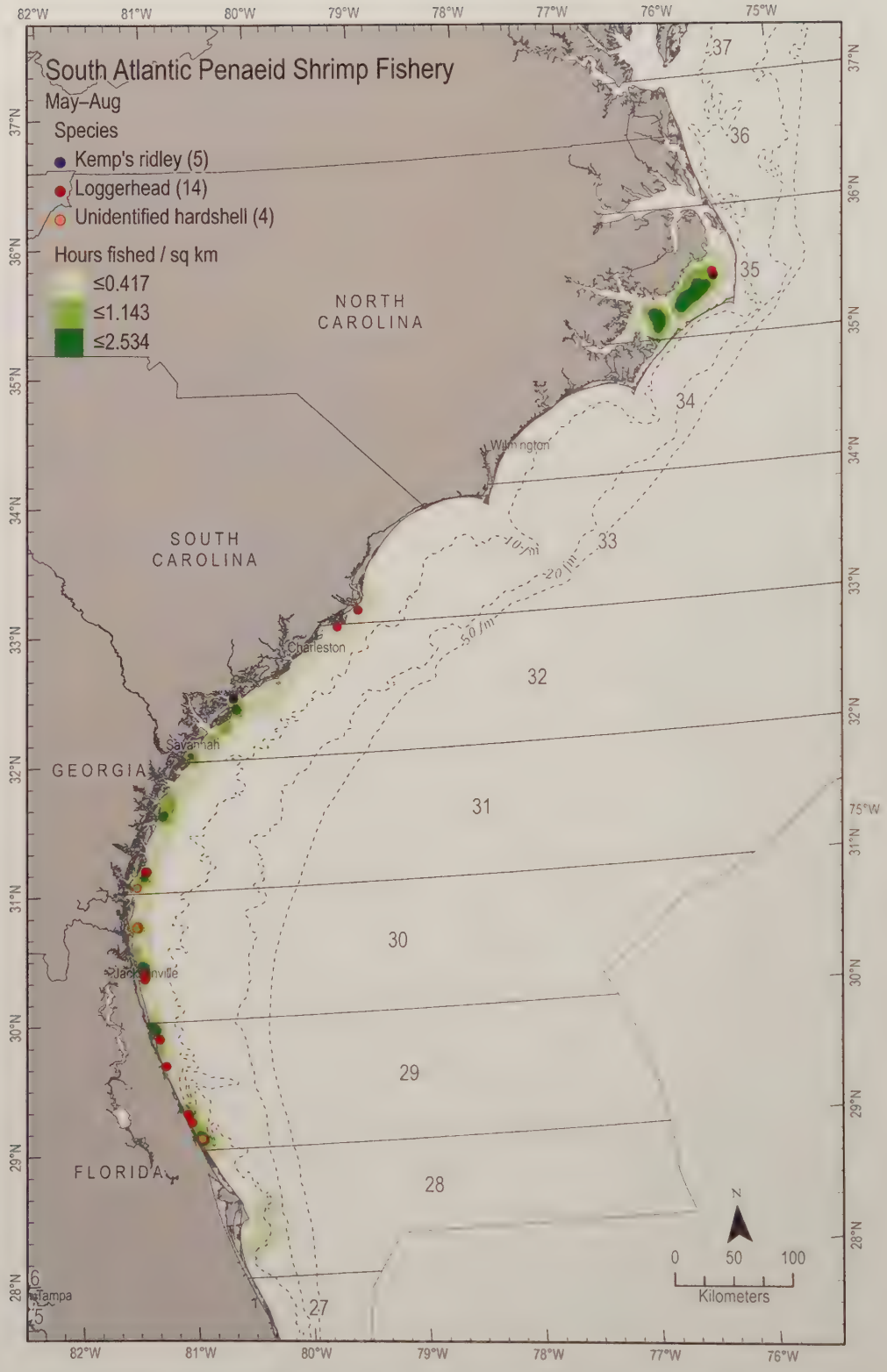

Figure 8.—Density of hours fished and sea turtle captures (n = 23), May through August, for the U.S. south Atlantic penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

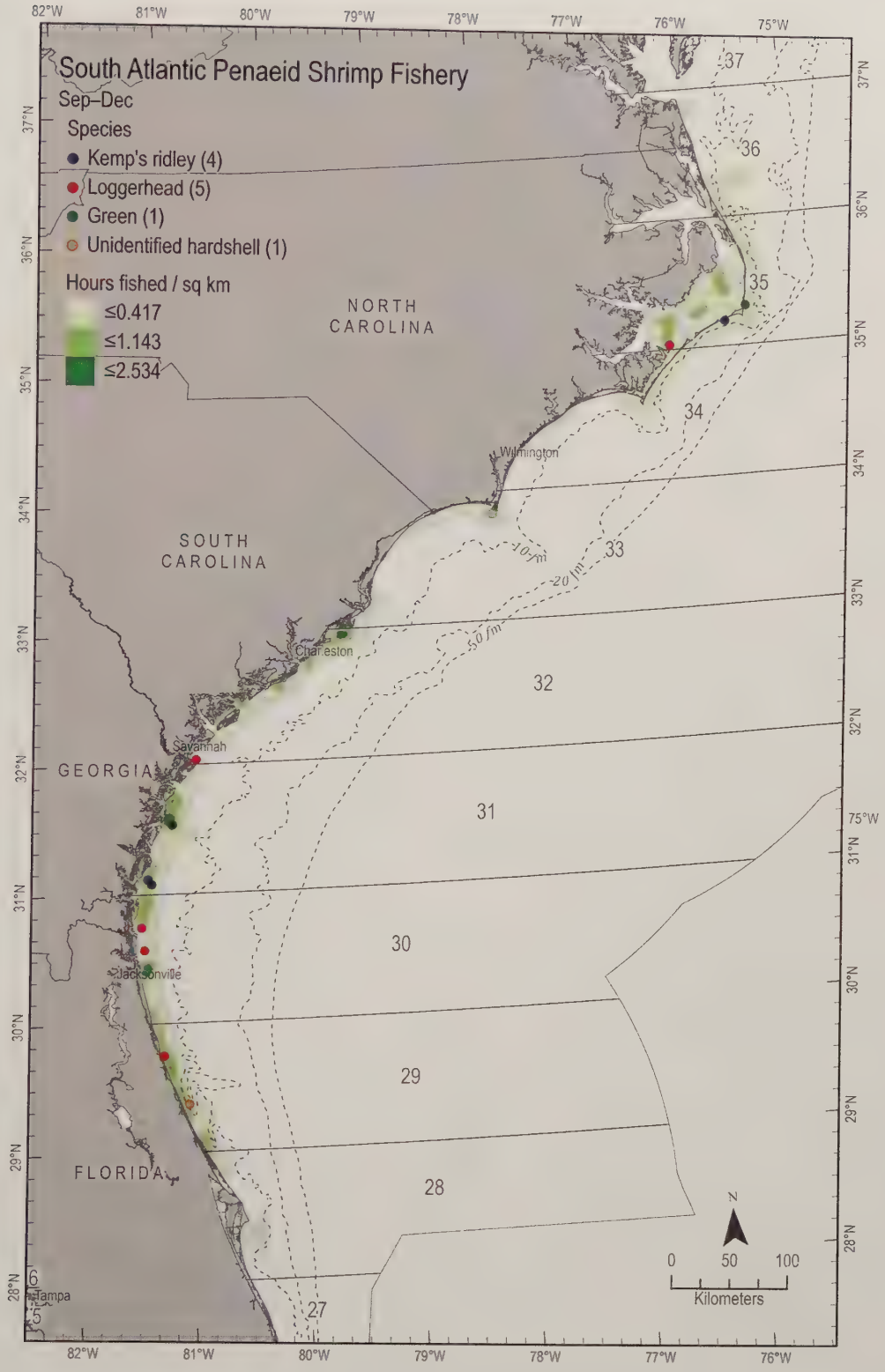

Figure 9.—Density of hours fished and sea turtle captures (n = 11), September through December, for the U.S. south Atlantic penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

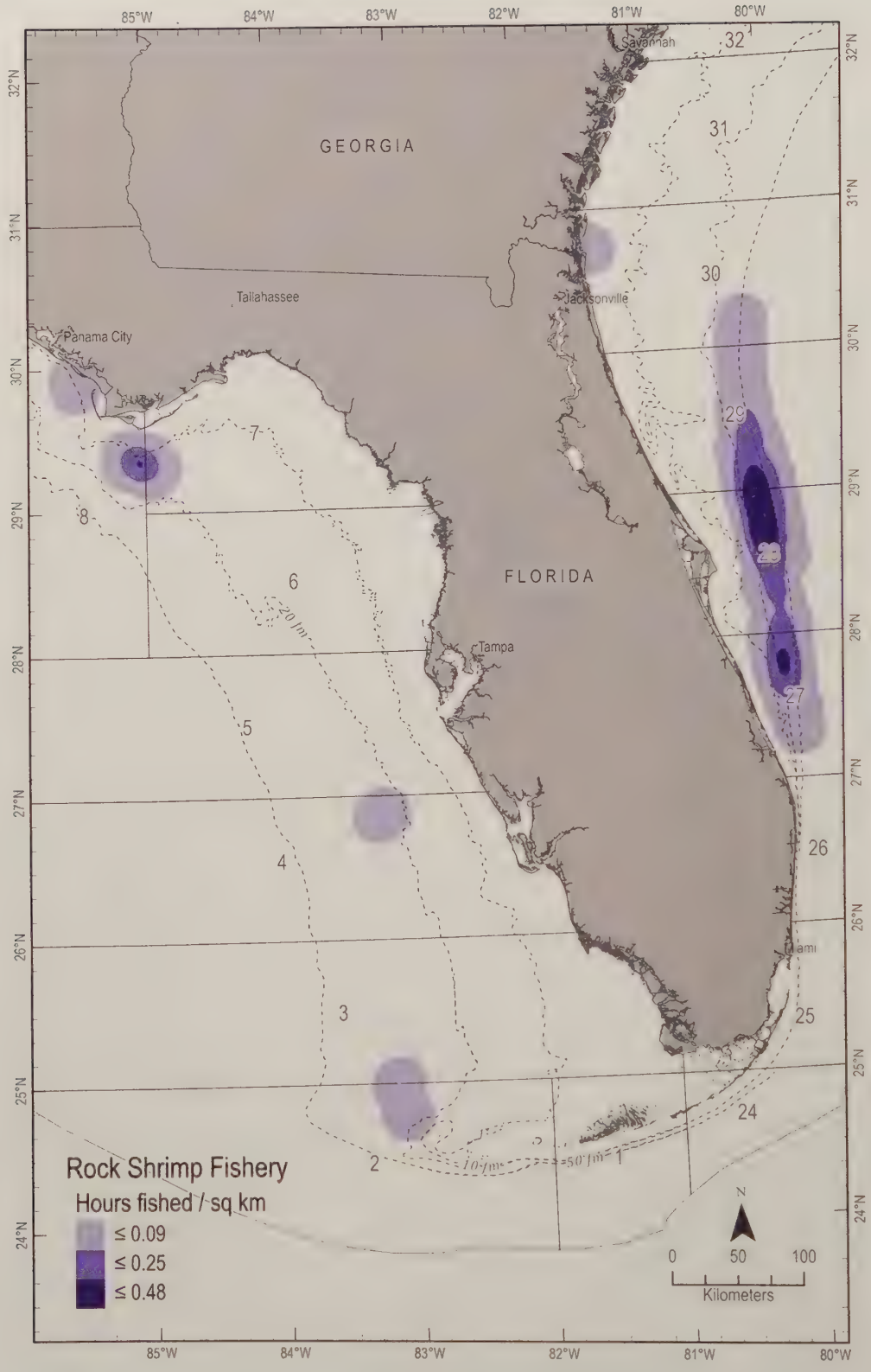

Figure 10.—Density of hours fished for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

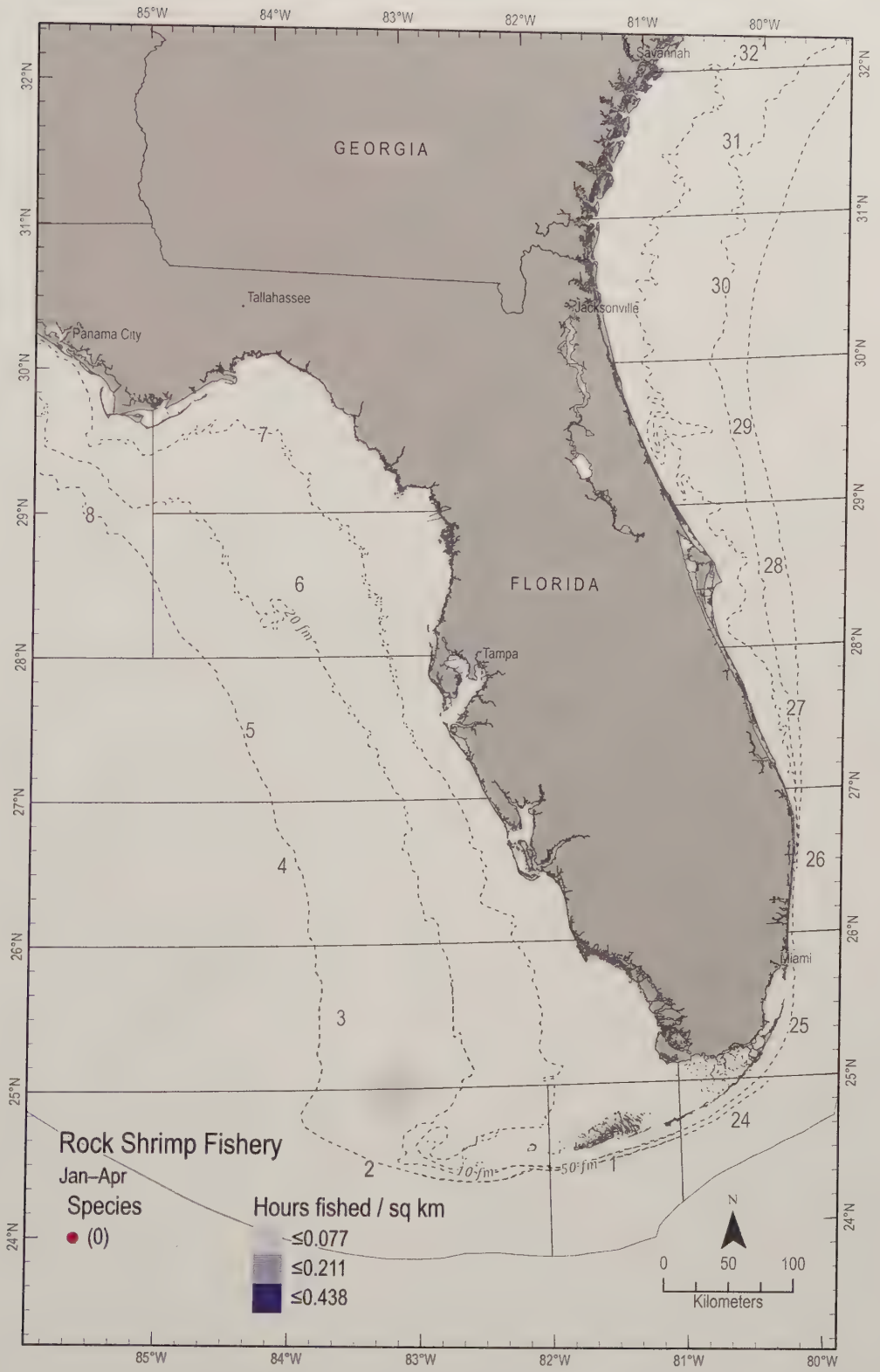

Figure 11.—Density of hours fished and sea turtle captures ($n = 0$), January through April, for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

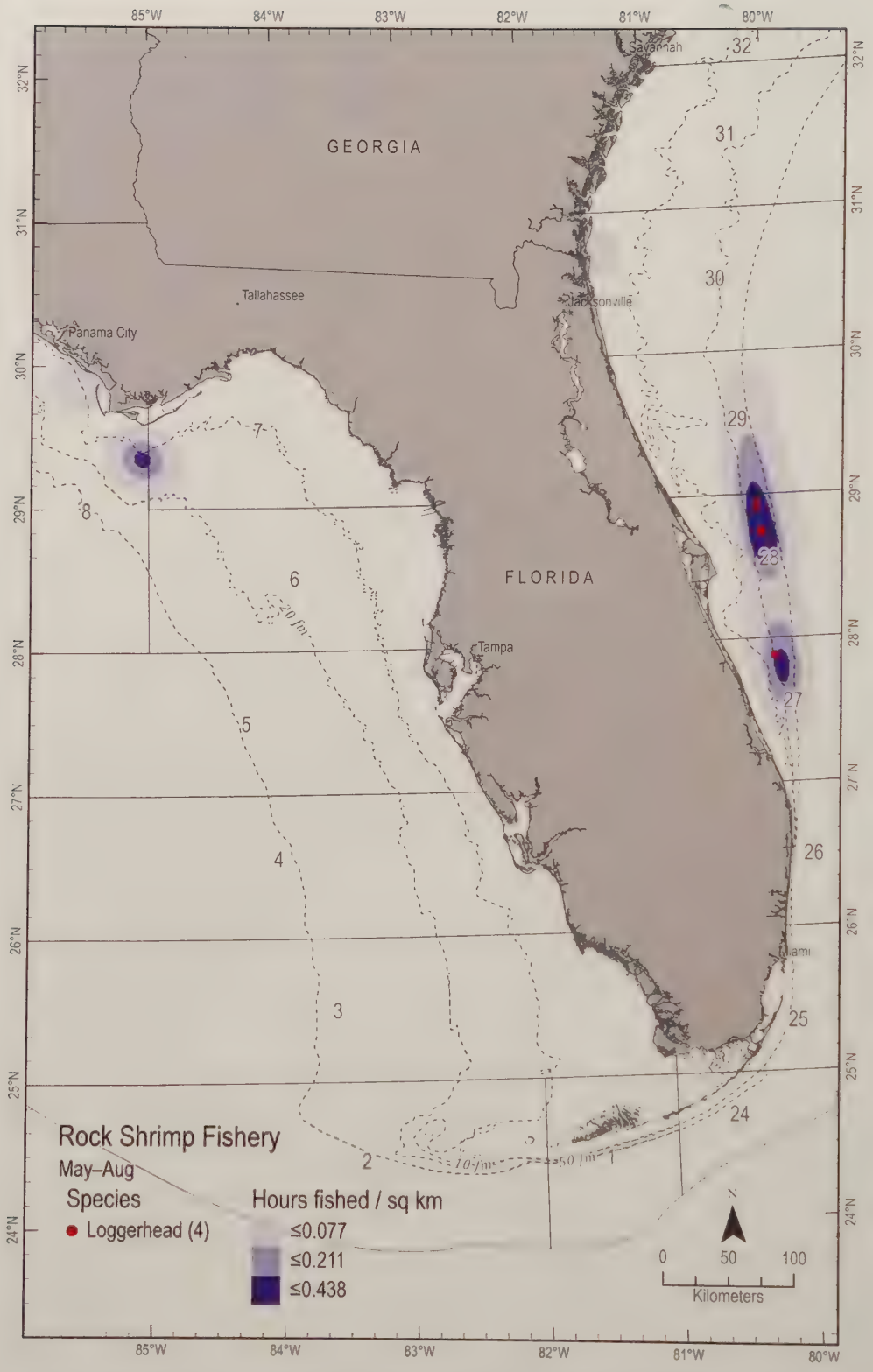

Figure 12.—Density of hours fished and sea turtle captures ($n = 4$), May through August, for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

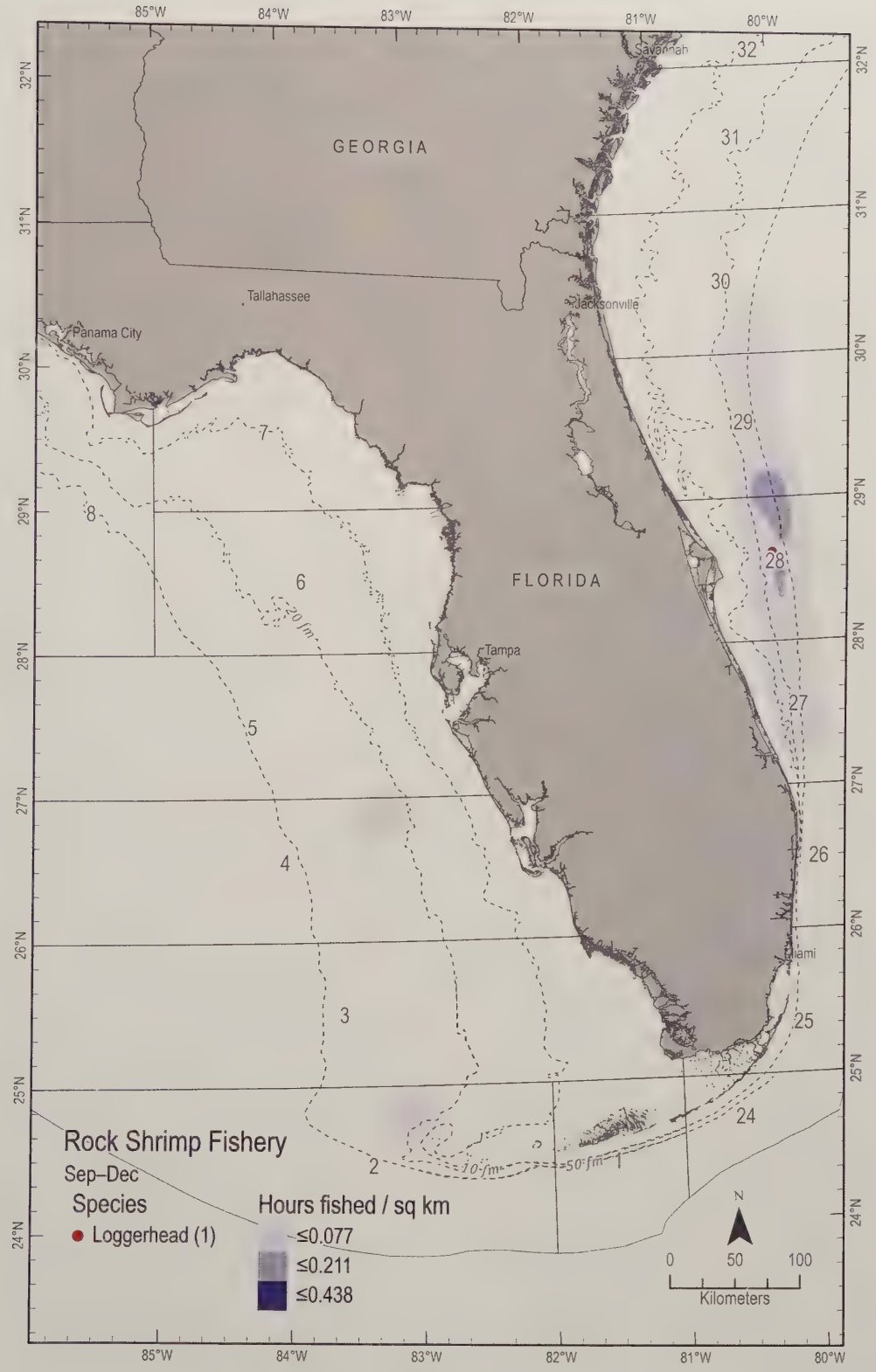

Figure 13.—Density of hours fished and sea turtle captures (n = 1), September through December, for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

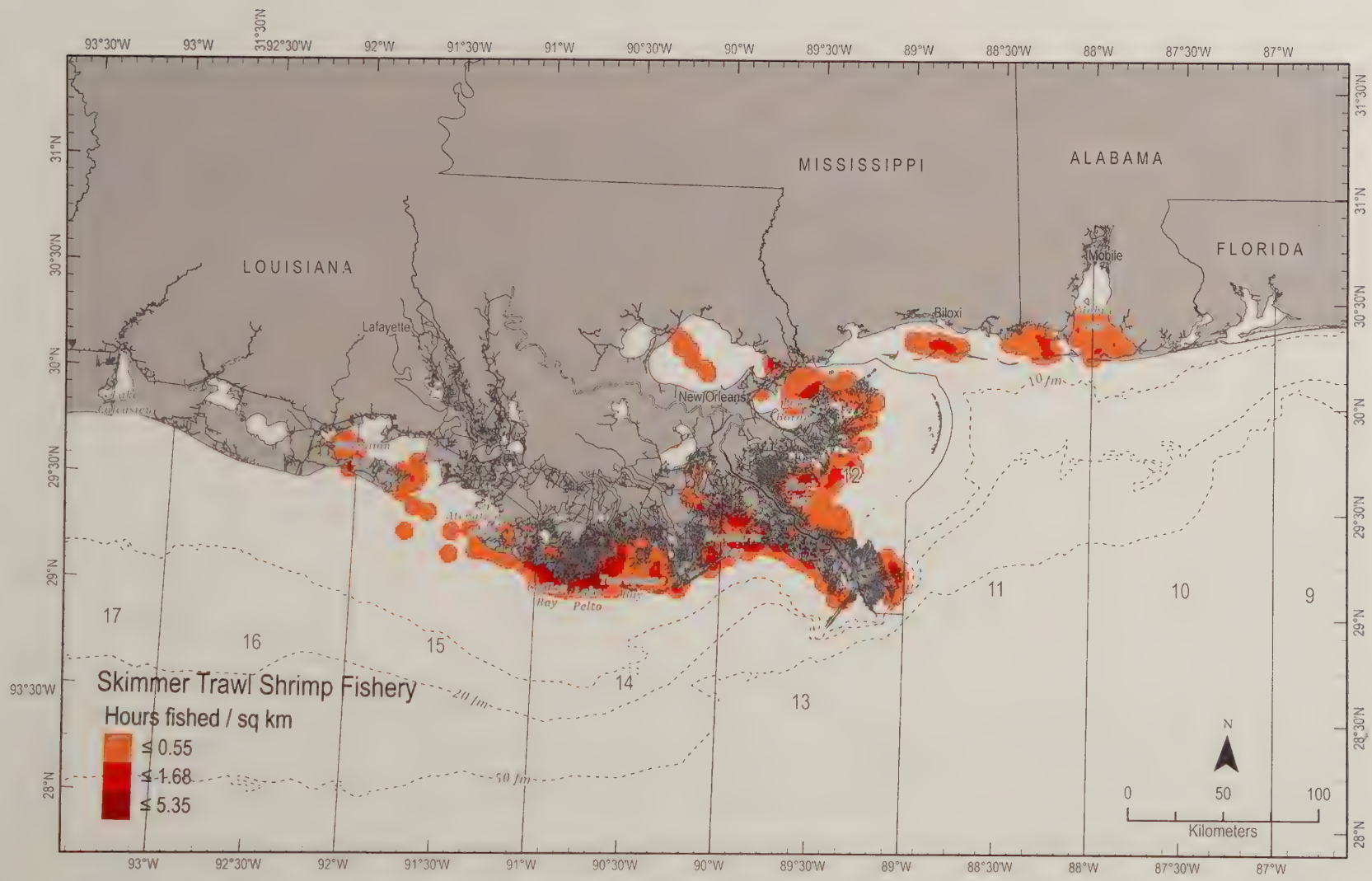

Figure 14.—Density of hours fished for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

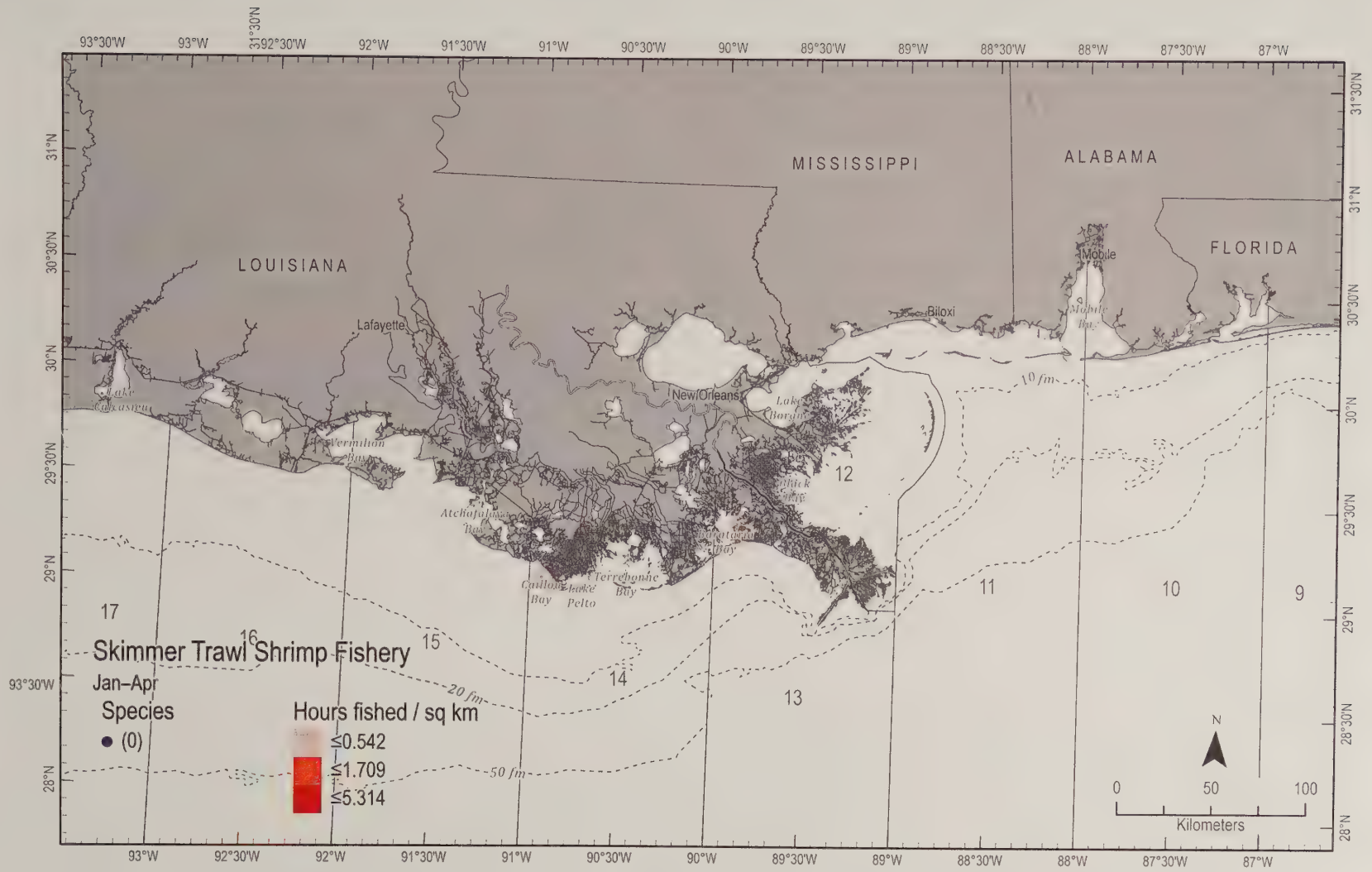

Figure 15.—Density of hours fished and sea turtle captures (n = 0), January through April, for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

son 3) (Fig. 3–5). Most sea turtle captures occurred off Louisiana, Texas, and the southern waters of west Florida. This was consistent with areas of high fishing effort and confirmed based on the optimized Hot Spot Analysis with clusters of significantly high sea turtle CPUE ($p<0.01$; Fig. 18). The predominate species of turtles captured during January–April, and May–August, were Kemp's ridleys and loggerheads. Interactions with green sea turtles were relatively consistent across the three seasons, with the largest number of captures in Texas waters.

Of the 178 turtles captured by the Gulf shrimp fishery, 77% (n = 137) were released alive after being worked up for biological samples. One hundred and nineteen turtles had a capture condition of alive, 51 were captured as fresh dead/unresponsive, of these, 135 or 79% were released alive (Table 2). Kemp's ridleys made up the majority of the species captured for a total of 72 followed by loggerheads at 53. Of the 52 loggerheads captured alive or fresh dead/unresponsive, 50 were released alive. Kemp's ridleys had a successful release rate of 83%. Of the 71 Kemp's ridley turtles captured alive or fresh dead/unresponsive 59 were released alive. A total of 28 greens were captured alive or fresh dead/unresponsive, of those, 12 (43%) were released alive; the lowest percentage of all the species.

Under field conditions, it was difficult to discern between unresponsive and dead turtles. Twenty-three turtles were released discarded dead/unresponsive. To decrease the chances of double reporting, discarded carcasses were marked with metal flipper tags and orange spray paint applied to the carapace in the shape of an X. In cooperation with the NMFS Office of Protected Resources (OPR), the carcasses of 9 additional turtles captured dead (6 greens and 3 Kemp's ridleys) were retained and returned to port to be examined for decompression sickness (see García-Párraga et al., 2014). Unknown status at capture and release was the result of the observer being unable to determine or observe the condition of the specimen.

Southeastern U.S. Atlantic Shrimp Fishery The southeastern U.S. Atlantic shrimp fishery generated 39 captures of the following species: loggerhead, Kemp's ridley, unidentified hardshell, and green. Thirty-eight of those were captured and released alive (Table 2). The fishery's final capture was an unidentified hardshell that was captured and released with an unknown status. The highest concentration of captures occurred in season 2 (May–August) off the coast of eastern Florida and Georgia, followed by season 3 (September–December). The lowest concentration of captures occurred in season 1 (Fig. 7–9). Loggerheads were the predominant species involved in interactions with the fishery, followed by Kemp's ridley. A cluster of significantly high ($p<0.01$) sea turtle CPUE was evident off the Georgia coast in the lower portion of statistical zone 31 (Fig. 19).

Rock Shrimp Fishery Five loggerhead sea turtles were captured and released alive in the rock shrimp fishery (Table 2). At the beginning of the season, between May and August off the coast of eastern Florida, 4 loggerheads were captured. The final loggerhead was captured between September–December in the same location (Fig. 11–13). There was no significant clustering of high or low sea turtle CPUE values (Fig. 20).

Skimmer Trawl Fishery The skimmer trawl fishery captured 58 sea turtles; 56 had a capture status of alive or fresh dead/unresponsive and 53 of those were released alive (Table 2). There were also two reports of previously dead (rotting flesh and crushed shell), specimens that died not as a result of current fishing (1 Kemp's Ridley, 1 green). Kemp's ridleys comprised the largest number of captures for this fishery at a total of 48; 46 of the 47 with a capture status of alive or fresh dead/unresponsive were released alive. Seasonal coverage of the skimmer trawl fishery generally begins in May. The peak season, between the months of May and August, resulted in the highest number of captures. Kemp's ridley was the predominate species captured in shallow waters of coastal Louisiana. No interactions were reported between January and April. (Fig. 15–16). Based on optimized Hot Spot Analysis, clusters of significantly high values of sea turtle CPUE ($p<0.01$) were found in the shallow waters just south of the Mississippi River Delta (Fig. 21).

Marine Mammal Characterization

Sixteen marine mammal interactions occurred, during mandatory coverage, 11 bottlenose dolphins, 3 unidentified dolphins, and 2 decomposed unidentified marine mammals (Table 3). All interactions with marine mammals occurred in the Gulf shrimp fishery, resulting from entanglement during trawling operations. Three bottlenose dolphins and 1 unidentified marine mammal were captured in the body of the shrimp net. The remaining 8 bottlenose dolphins were captured in various portions of the shrimp net configuration, 7 in the lazy line, and one in the leg line. The final unidentified marine mammal was entangled in a try net; it was decomposing prior to capture and showed evidence of bite marks on the carcass. Two unidentified dolphins were captured in the lazy line, and one decomposing carcass was captured in the tickler chain. The majority of marine mammals were captured off the coasts of Texas and Louisiana and one west of the Straits of Florida (Fig. 22). All but two of the marine mammals were released dead after being removed from the gear. Of the two that swam away after release, one dolphin captured in the body of the net swam away abnormally. The second, an unidentified dolphin, was tangled in the lazy line and swam away normally at release.

Sawfish Characterization

Seventeen sawfish were captured off Florida's coast, 12 were identified to the species level, smalltooth sawfish. The Gulf shrimp fishery captured 14, the southeastern U.S. Atlantic shrimp fishery captured 2, and 1 was captured by the rock shrimp fishery. All but one was captured in standard

Table 3.—Protected species capture and release status based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

Type Species Disposition	Fishery Gulf penaeid otter trawl	South Atlantic penaeid otter trawl	Rock	Skimmer trawl	Total
Birds	9	3		3	15
Brown pelican	3	2			5
Discarded dead/unresponsive carcass	3	2			5
Laughing gull				3	3
Discarded dead/unresponsive carcass				3	3
Pelican	1				1
Discarded dead/unresponsive carcass	1				1
Unidentified songbird	1				1
Discarded dead/unresponsive carcass	1				1
Unknown bird	4	1			5
Discarded dead/unresponsive carcass	4	1			5
Giant manta ray	2	6			8
Released alive		4			4
Unknown	2	2			4
Sawfish	14	2	1		17
Smalltooth sawfish	11	1			12
Discarded dead/unresponsive carcass	1				1
Released alive	6				6
Unknown	4	1			5
Sawfish spp.	3	1	1		5
Discarded dead/unresponsive carcass	1		1		2
Released alive	2	1			3
Sturgeon	2	12			14
Atlantic sturgeon		9			9
Discarded dead/unresponsive carcass		3			3
Released alive		6			6
Gulf sturgeon	1				1
Released alive	1				1
Sturgeon spp.	1	3			4
Released alive	1	3			4
Marine mammals	16				16
Bottlenose dolphin	11				11
Alive, swam away abnormally	1				1
Dead	10				10
Unidentified dolphin	3				3
Alive, swam away normally	1				1
Dead	2				2
Unidentified marine mammal	2				2

shrimp nets; the final capture was in a Gulf shrimp vessel's try net. Of the captured sawfish in the Gulf of Mexico fishery, 11 were smalltooth sawfish, and 6 were released alive, 1 was released dead/unresponsive, and 4 were released with unknown status (including the specimen captured in the try net; Table 3). The majority of the Gulf shrimp captures occurred in statistical zones 1 and 2 off the Florida Keys, and the final capture occurred in statistical zone 4 (Fig. 23). Of the two sawfish captured in the southeastern U.S. Atlantic shrimp fishery, one sawfish was released alive, and one smalltooth sawfish was released with an unknown status off the coast of Port Canaveral in statistical zone 28. The sawfish captured by the rock shrimp fishery occurred in statistical zone 29 and was discarded as a dead/unresponsive carcass.

Giant Manta Ray Characterization

In 2019, the observer program began recording giant manta ray capture data, and during that year, eight were captured; two were caught in the Gulf shrimp fishery and six in the southeastern U.S. Atlantic shrimp fishery. The two caught in the Gulf shrimp fishery were released with an unknown status off Louisiana's coast, statistical zone 13 (Table 3, Fig. 23). The six captured in the southeastern U.S. Atlantic shrimp fishery were caught off Georgia's coast; four were released alive and two with unknown status. Exact GPS coordinates were not available for giant manta rays captured off the coast of Georgia; however, all specimens were captured during the same trip. Based on that trip's general location, it was determined the captures occurred in Georgia waters at depths of 24–31 ft in statistical zone 31.

Sturgeon Characterization

Fourteen sturgeons, *Acipenser* spp., were captured throughout the observer program, two by the Gulf shrimp fishery and twelve by the southeastern U.S. Atlantic shrimp fishery (Table 3). Nine of the specimens caught by the southeastern U.S. Atlantic shrimp fishery were released alive; the remaining three were discarded/dead unresponsive. All twelve were captured off the east coast ranging from statistical zones 31 to 35 (Fig. 23). The two specimens caught by the Gulf shrimp fishery were captured in statistical zones 11 and 12; both were released alive.

Seabird Characterization

The incidental capture of 15 individual birds were reported; 9 from the Gulf shrimp fishery, 3 from the southeastern U.S. Atlantic fishery, and 3 from the skimmer trawl fishery (Table 3). The following species were reported, 5 brown pelicans, *Pelecanus occidentalis*, 3 laughing gulls, *Leucopaeus atricilla*, 1 pelican, *Pelecanus* spp., 1 unidentified songbird, and 5 unknown bird species. Brown pelicans were captured by both the Gulf shrimp and southeastern U.S. Atlantic shrimp fisheries. The three captured by the Gulf shrimp fishery were caught in statistical zones 11, 14, and 15 (Fig. 23). Captures by the southeastern U.S. Atlantic shrimp fishery occurred in statistical zones 29 and 32. Three laughing gulls were captured by the skim-

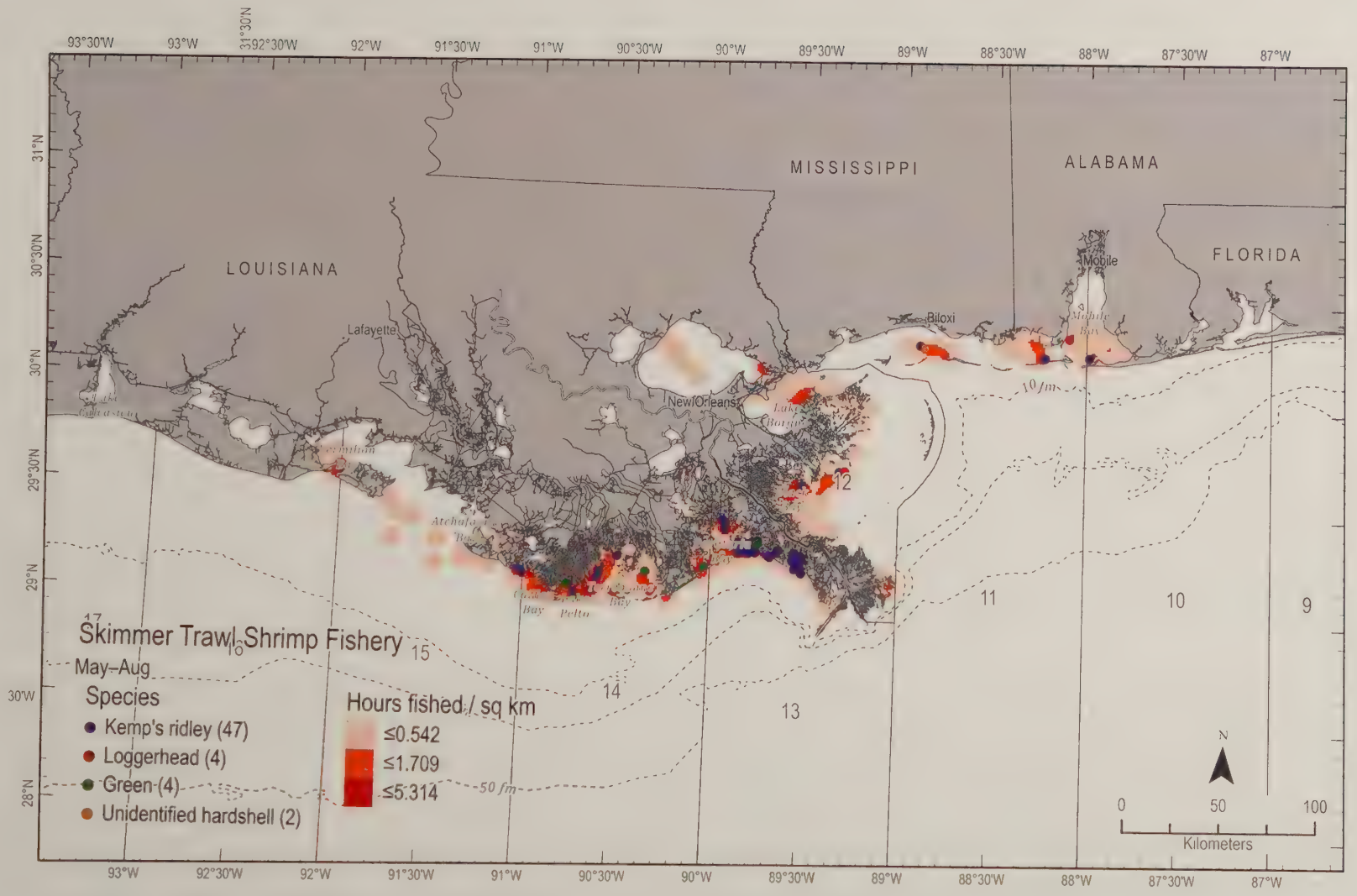

Figure 16.—Density of hours fished and sea turtle captures (n = 57), May through August, for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

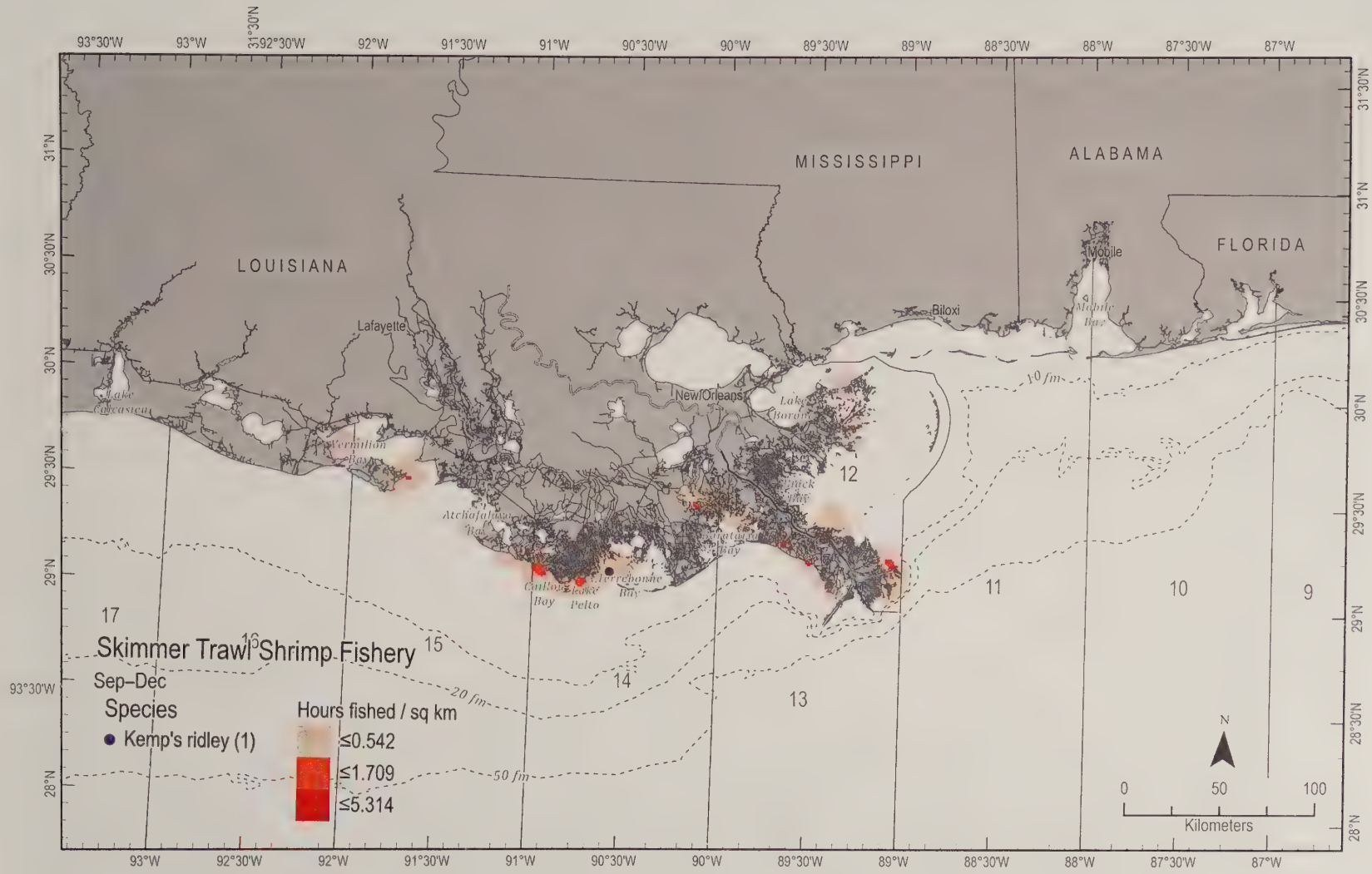

Figure 17.—Density of hours fished and sea turtle captures (n = 1), September through December, for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

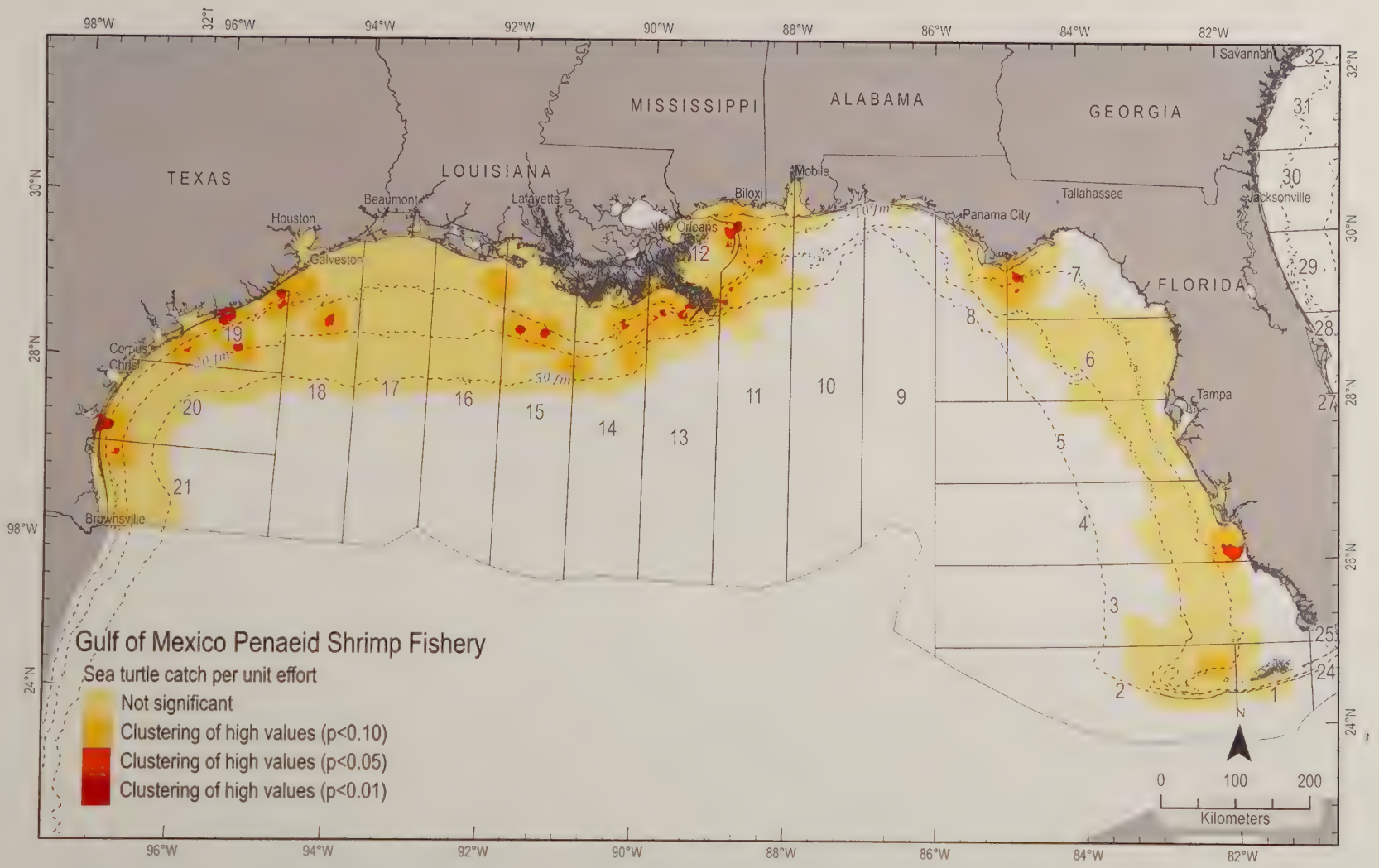

Figure 18.— Getis-Ord Gi* (Hot Spot) analysis of sea turtle CPUE for the U.S. Gulf of Mexico penaeid otter trawl shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

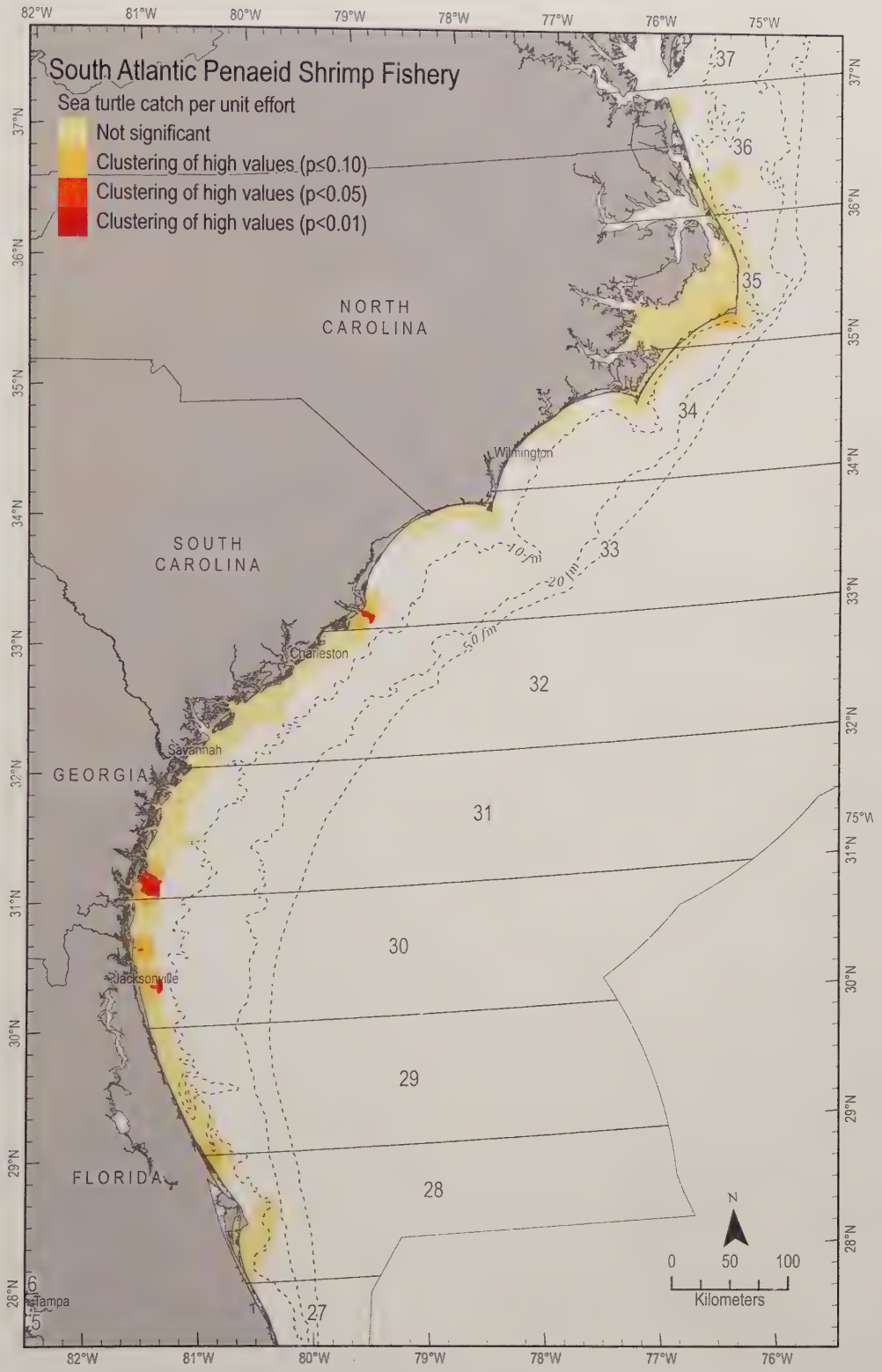

Figure 19.— Getis-Ord Gi* (Hot Spot) analysis of sea turtle CPUE for the U.S. south Atlantic penaeid shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

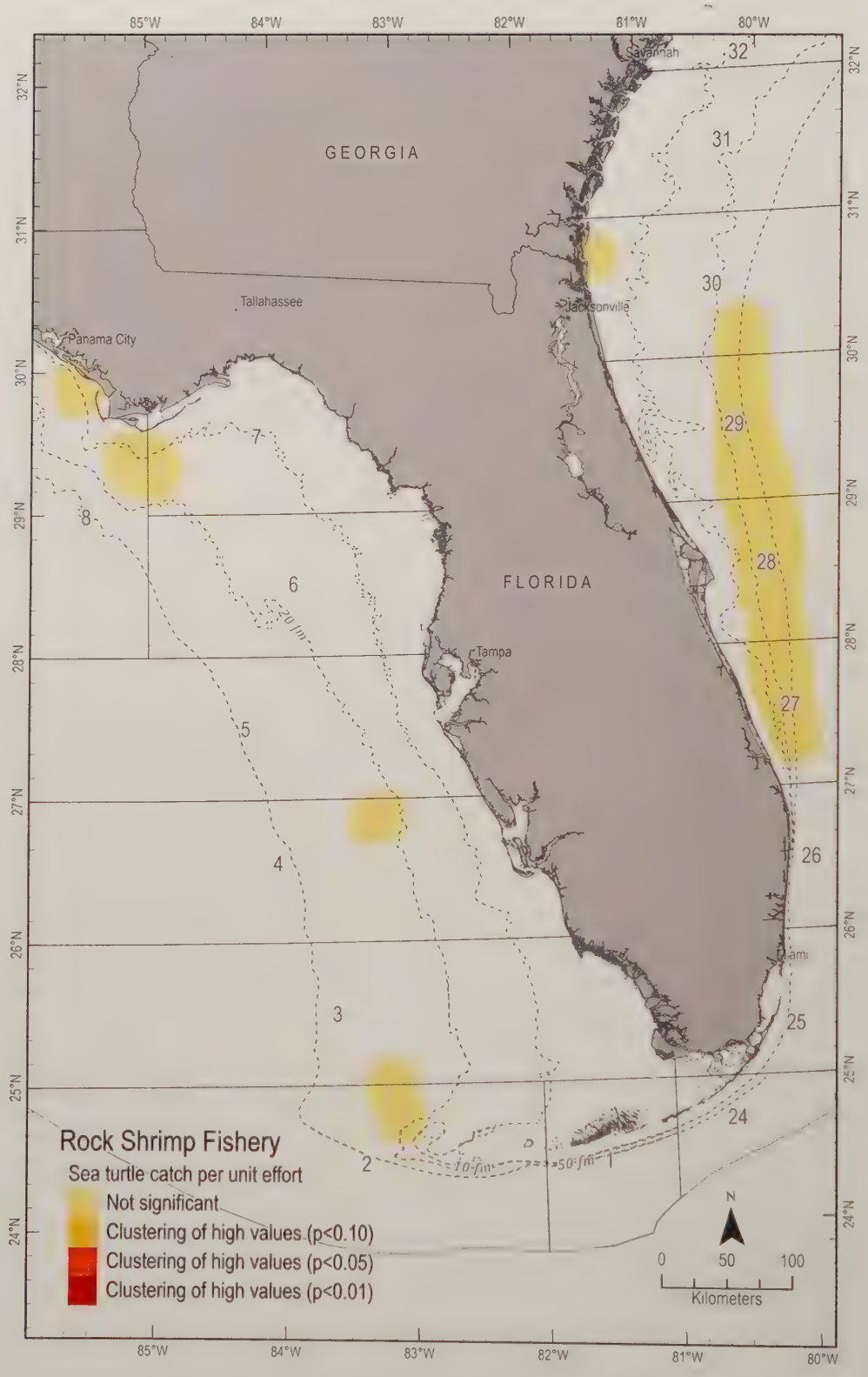

Figure 20.— Getis-Ord Gi* (Hot Spot) analysis of sea turtle CPUE for the rock shrimp fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from June 2008 through December 2019.

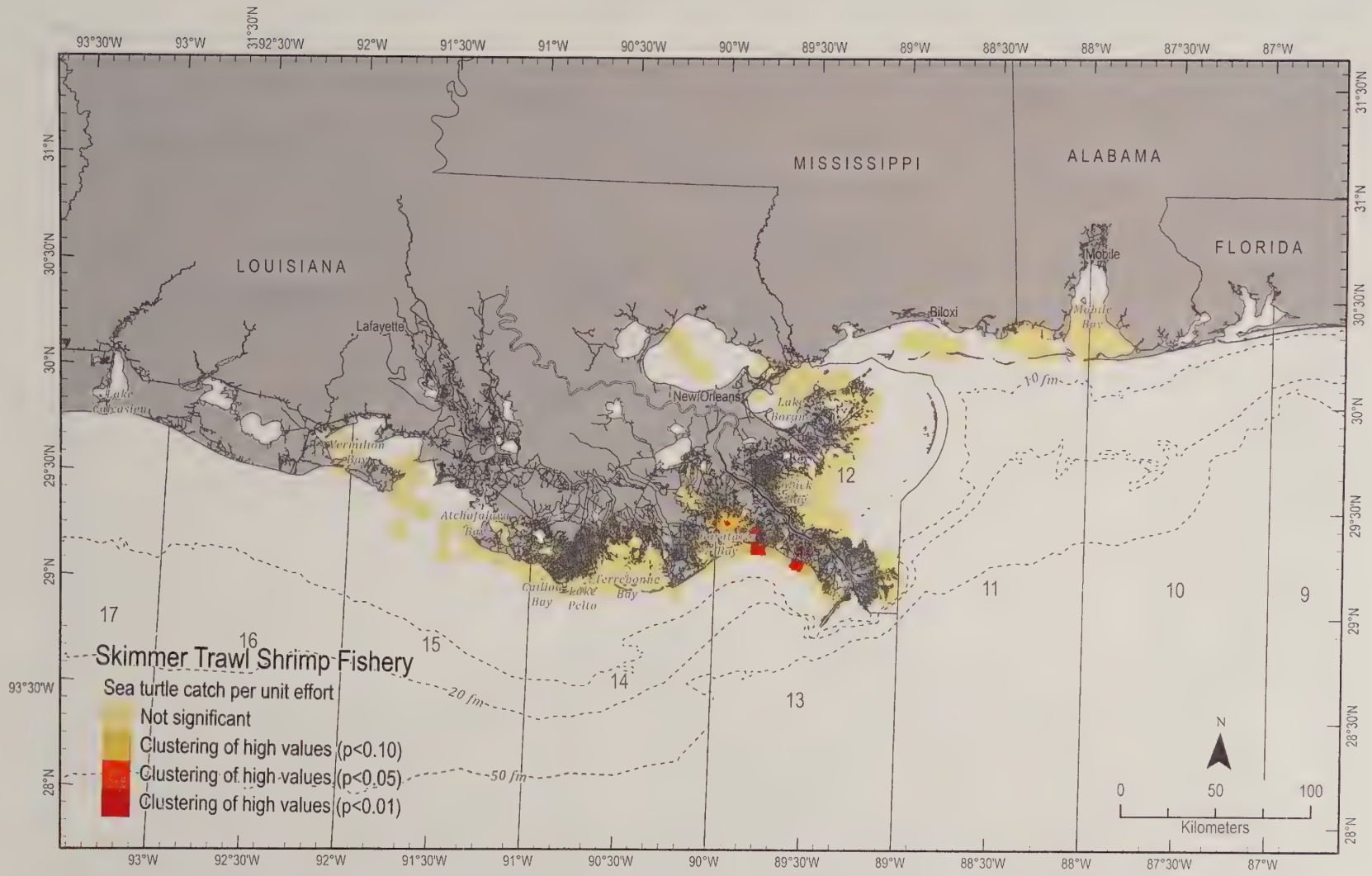

Figure 21.— Getis-Ord Gi* (Hot Spot) analysis of sea turtle CPUE for the skimmer trawl fishery based on mandatory observer coverage of the U.S. southeastern shrimp fishery from May 2012 through December 2019.

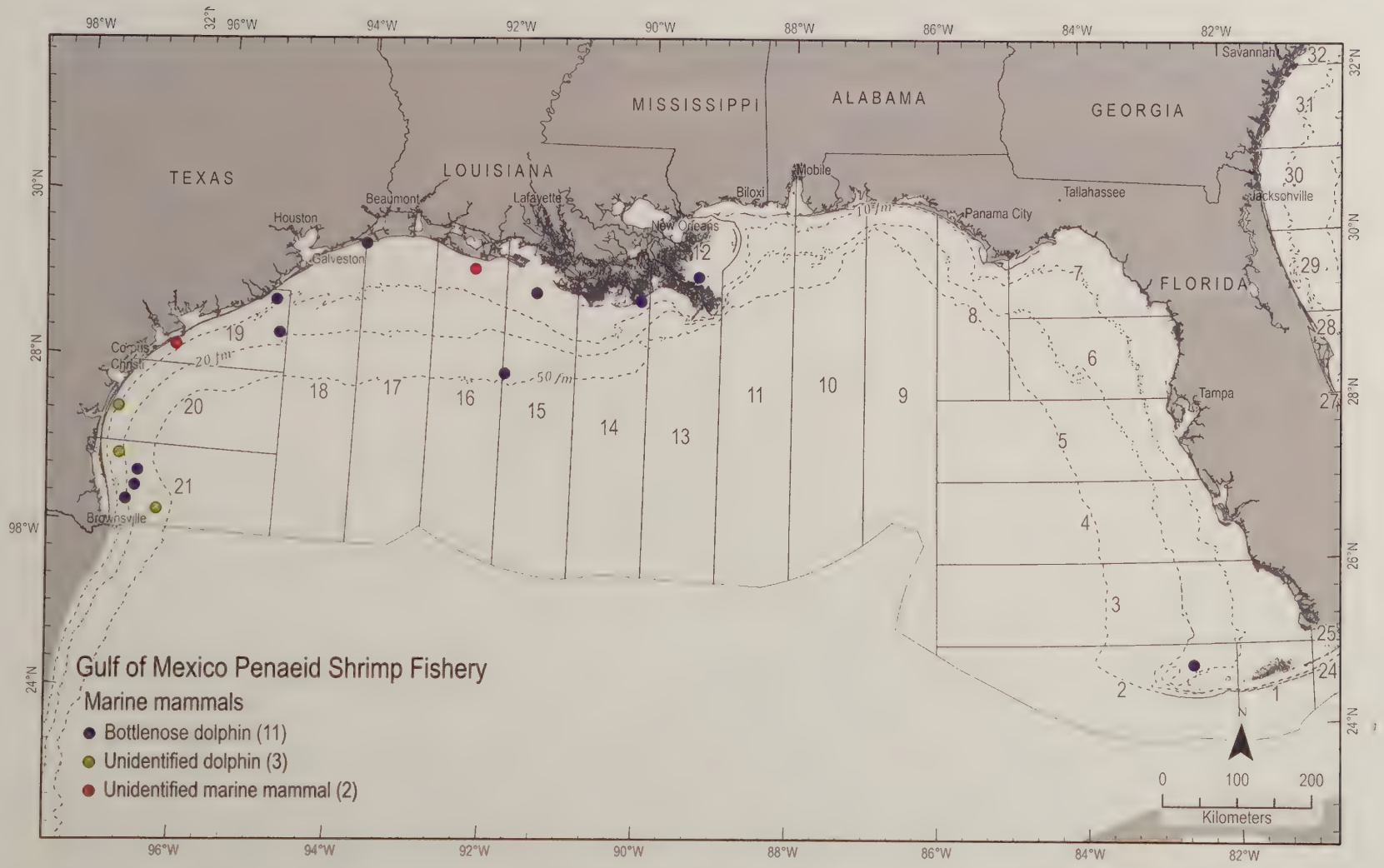

Figure 22.—Locations of marine mammal captures (n = 16), based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

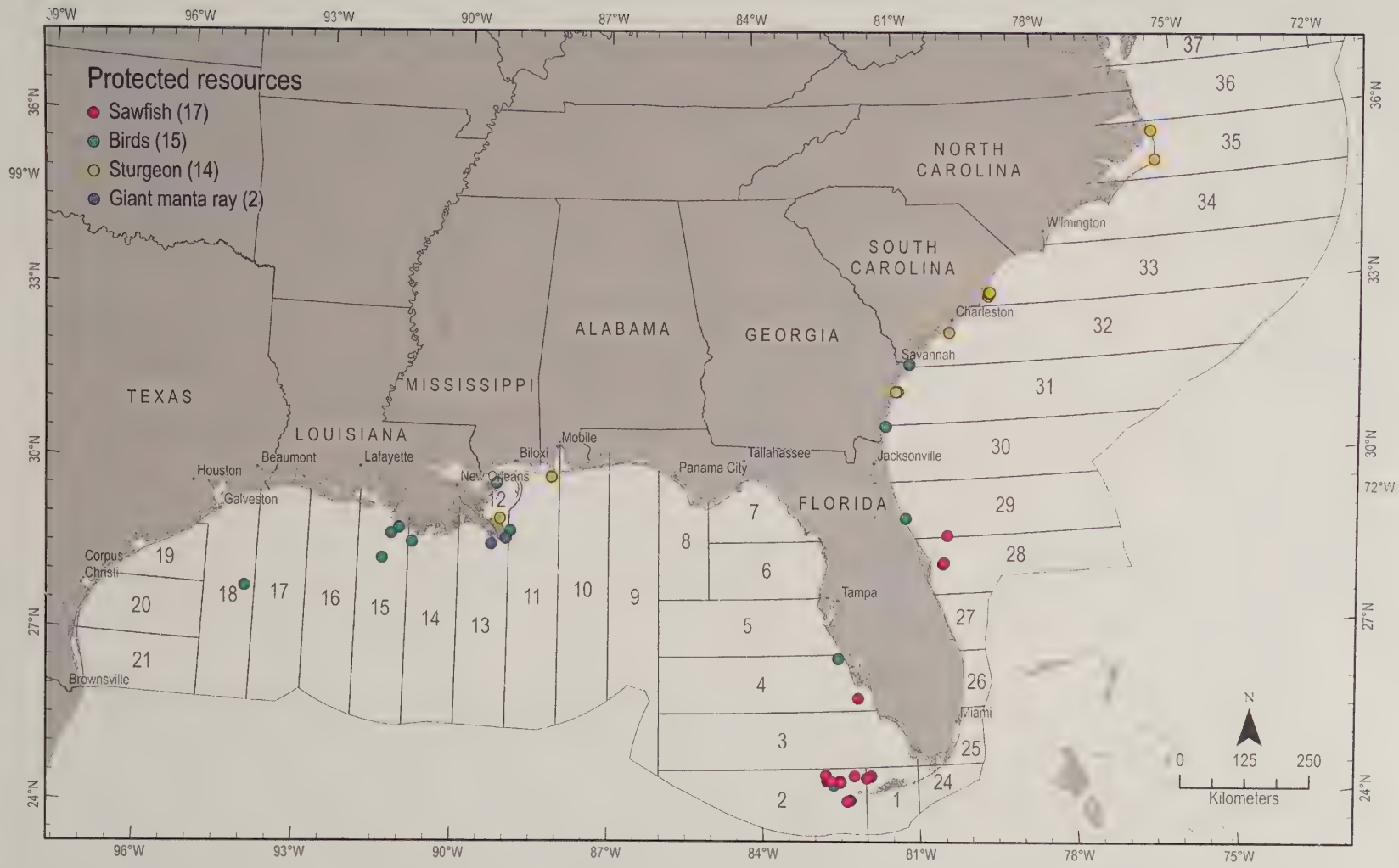

Figure 23.—Locations of protected species captures (n = 48), based on mandatory observer coverage of the U.S. southeastern shrimp fishery from July 2007 through December 2019.

mer trawl fishery off Louisiana's coast in statistical zone 12 during one trip. A bird identified as pelican, *Pelecanus* spp., was captured by the Gulf shrimp fishery in statistical zone 2 off west Florida and an unidentified songbird in statistical zone 18. The remaining five unknown species were split between the Gulf and southeastern U.S. Atlantic shrimp fisheries, with three captures in statistical zone 15 off the coast of Louisiana, 1 in statistical zone 4 off the west coast of Florida, and 1 off Georgia's coast in statistical zone 30.

Discussion

Observer coverage, fishing effort, and protected species interactions fluctuated from 2007 to 2019; this was primarily due to funding and additional fisheries that split observer coverage over time. During the observer program's mandatory coverage of 1,766 shrimp trips, a total of 280 sea turtles, 16 marine mammals, 8 giant manta rays, 17 sawfish, 14 sturgeons, and 15 seabird interactions were documented. Captures were divided between four mandatory coverage fisheries: Gulf shrimp, southeastern U.S. Atlantic shrimp, rock shrimp, and skimmer trawl. Approximately 90% of observer coverage, by sea days, occurred in the Gulf shrimp fishery (Table 1). The spatial distribution of incidental captures was consistent with fishing effort and fishery distribution. Further research will be needed to determine if species-specific rate of capture is influenced by spatial and seasonal distribution of fishing effort.

Fishing effort in the Gulf shrimp fishery was concentrated off Texas and Louisiana's coasts, coinciding with the largest quantity of sea turtle interactions in those zones (Fig. 2). Interactions with sea turtles (Fig. 3–5) were highest during season 1 from January to April, with a slight decrease in season 2 from May to August. Of those, 137 sea turtles were released alive (Table 2). Fishing grounds in both state and federal waters off the Texas coast are closed yearly for an approximate 60-day period during May–July to allow shrimp to reach an economically valuable size and to decrease bycatch of immature shrimp. Research has determined the closure of Texas waters plays a positive role by temporarily decreasing sea turtle interactions during May–August (Crowder et al., 1995; Caillouet et al., 1996; Shaver and Caillouett, 1998; Lewison et al., 2003).

The southeastern U.S. Atlantic shrimp fishery showed spatial distribution of fishing effort from North Carolina down the coast to Cape Canaveral, Fla., with high concentrations in North Carolina off Pamlico Sound. Sporadic clusters of concentration from north Florida to Charleston, S.C. (Fig. 6) were evident. Season 2, from May to August, resulted in the highest sea turtle interactions (n = 23) (Fig. 7–9), consistent with the distribution of fishing effort. A total of 39 sea turtle interactions occurred, all but one was released alive (Table 2).

One percent of the observer program's effort was dedicated to the rock shrimp fishery (Table 1); however, the positive spatial distribution of sea turtle interaction, fishing effort, and fishing seasonality was evident (Fig. 11–13). The low percent coverage was a direct reflection of the small size of the fishing fleet, short fishing season, and geographic limitations due to species habitat. All five of the loggerhead turtles captured in the fishery were released alive (Table 2).

Coverage of the skimmer trawl fishery, 2012–19, made up 3% of the sea days by year and fishery for the combined years of coverage across all four fisheries (Table 1). Fishing effort was highly concentrated in the shallow waters off Louisiana and around the Mississippi River Delta (Fig. 14). Fishing seasons began in May, the largest volume of effort occurred during May through August (Fig. 15–17). The observer program's percent coverage was low at 3%; however, the fishery exhibited a large volume of sea turtle interactions, a total of 58 captures, when compared to the number of captures in relation to sea days by year and fishery for the other fisheries (Table 2). The areas fished also presented a possible species richness during the fishing season with 48 Kemp's ridley captures. Survival rates were also high; 53 of the 58 interactions were released alive, possibly a direct result of the fisheries' short tow times. The shorter tow times and frequent tail bag retrieval may result in higher survival rates (Coale et al., 1994). At the time of this research, skimmer trawls were not required to have TED's. Beginning 1 Aug. 2021, skimmer trawl vessels of 40 feet and greater in length that are rigged for fishing were required to install TED's (NOAA, 2019).

Concerning observed survival rates, marine mammals are the most adversely affected. Dolphins are known to forage and inhabit areas around active shrimp trawls, resulting in gear entanglement and death if captured (Fertl, 1994; Fertl and Leatherwood, 1997; Kovacs and Cox, 2014; Siegel, et al., 2015; Moreno and Mathews, 2018). The incidental capture of marine mammals was low, 16 over a 13-yr period; however, 14 of those interactions resulted in death (Table 3), with forced submergence due to entanglement in fishing gear being the likely cause of death.

Birds, also highly common around shrimp vessels, are unlikely to survive an interaction. Various species of birds are common around active shrimp trawlers, attracted to fishing operations to feed on discarded bycatch as it is dumped overboard (Wickliffe and Jodice, 2010; Jodice, et al., 2011). Fifteen captures of no significant spatial distribution were reported over the 13-yr period. The number of bird captures reported here were low; observers were required to report all bird captures. A bird's ability to fly away from active fishing gear may be a contributing factor to the low numbers.

Giant manta rays, a recent addition to the observer program's reporting requirements, showed higher rates of interaction in the southeastern U.S. Atlantic shrimp fishery than the Gulf shrimp fishery. Of the eight reported interactions, four were released alive (Table 3). These numbers are likely to increase as reporting continues; reported captures to date were the re-

sult of two independent fishing trips in 2019.

The spatial distribution of sturgeon interaction was limited by habitat ranges. Gulf and Atlantic sturgeon hatch in freshwater streams, they migrate out to sea as juveniles and return as breeding adults. Of the fourteen reported interactions, eleven were released alive (Table 3). Observed recorded interaction with these species were low in number, with a favorable survival. Increased fishing and reporting efforts in and around their natural habitat, over time, may exhibit higher results.

Interactions with sawfish in the Gulf shrimp fishery occurred exclusively off the west coast of Florida; southeastern U.S. Atlantic shrimp fishery interactions were located off Port Canaveral, Fla.; rock shrimp captures occurred in statistical zone 29 off the east coast of Florida. This was consistent with habitat ranges for this species. Of the seventeen specimens captured, nine were released alive, five were released with unknown status (due to poor water visibility at time of release), and three were discarded dead.

The shrimp fishery produces high quantities of bycatch; the federal government works to regulate and sustain the fishery for future generations of consumers and fishermen. To further decrease bycatch, continued research is necessary to evaluate the effects of fishing on the environment and develop gear and methods to improve it. To date, success is evident with the development of BRD's, TED's, tow time restrictions, and area and fishery closures (Crowder et al., 1994; Crowder et al., 1995; Watson et al., 1999; Hall et al., 2000; Harrington et al., 2005; Keledjian et al., 2014; Scott-Denton et al., 2020). BRD's and TED's have reduced bycatch and interactions with sea turtles, aiding escape from active fishing. Length of forced submergence in shrimp gear has been decreased through tow time restrictions. Fishery closures allows stocks to mature and temporarily stop interaction with protected species.

Currently, given the non-selective nature of the shrimp fishery gear, interactions with protected species are inevitable. To conserve fish stocks and protected species for the future, continued efforts must be made to limit interactions and reduce mortality as a result of fishing efforts. The incidental mortality of long-lived marine species and the reduction of bycatch are topics of grave concern. Due to the low percentage of observer coverage, in terms of fishing effort and geographic distribution, protected species interactions are likely underreported; however, attempts are made to utilize available data (Epperly and Teas, 2002; Epperly et al., 2002; Scott-Denton et al., 2012; Wallace et al., 2013; Babcock et al., 2018). Moreover, advanced technology, notably electronic monitoring (EM), machine learning (ML), and artificial intelligence (AI) are being evaluated for use in Gulf of Mexico commercial fisheries to augment observer coverage levels.

The observer program's fluidity allows for expansion and the incorporation of outside research needs to aid in scientific research. Recent incorporations to the observer program include decompression sickness studies, post-interaction mortality research, and constant development of bycatch mitigation techniques. This also holds true for informing research needs resulting from natural disasters such as hurricanes and human-made disasters like the Deepwater Horizon Oil Spill.

Protected species mortality estimates are used to determine annual potential biological removal from various stocks. The observer program educates the industry regarding proper protected species handling and resuscitation techniques as well as the need to limit tow times and advance gear development. The advancement of gear development aids in increasing catch rates of target species while decreasing the capture of and/or increasing the survival rates of incidental catch. In addition, the presence of observers aboard the vessel may increase sea turtle survival rates through resuscitation effort prior to release.

Observer programs remain the most reliable means for monitoring commercial fisheries by providing unbiased, reliable, and high-quality data. Human observer coverage of the shrimp fisheries is minimal (approximately 2–3%); however, 100% coverage is not fiscally possible. Technological advancements in the form of EM and effort monitoring tools (vessel monitoring systems, electronic logbooks, and navigational vessel programs) will aid in increased coverage and assessment in the future. Collectively, these efforts will provide important insight on shrimp species and protected species CPUE, and life history characteristics for both target and non-target species.

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Exempted and Research Deep-Set Fishing Trials for Swordfish, *Xiphias gladius,* in the Southern California Bight, 2017–21

CHUGEY A. SEPULVEDA, MICHAEL S. WANG, and SCOTT A. AALBERS

Introduction

This work reports on the second phase of gear development research and exempted fishing trials for swordfish, *Xiphias gladius*, using deep-set fishing techniques within the Southern California Bight (SCB). Following recommendation from the Pacific Fisheries Management Council (PFMC), NOAA's National Marine Fisheries Service (NMFS) issued an exempted fishing permit (EFP) to the Pfleger Institute of Environmental Research (PIER) in August 2015 to test the use of an artisanal gear type designed to selectively target swordfish below the thermocline during the day (Sepulveda et al., 2014).

The initial EFP application included up to five independent cooperative fishing vessels and allowed them to target swordfish using deep-set buoy gear (DSBG), a hook and line gear type that was developed by PIER for targeting swordfish in the SCB (Sepulveda et al., 2014; Sepulveda and Aalbers, 2018). Cooperative fishermen selected for the EFP trials were chosen based on past experience level, willingness to participate in the research trials, and availability during the California swordfish season (August–December). Average experience level of the selected EFP participants using either harpoon or driftnet gear types was >18 yr.

During 2015–16, the first phase of exempted trials yielded relatively high selectivity for swordfish (>80%) with marketable catch making up > 98% of total landings (Sepulveda and Aalbers, 2018). Catch rates during the initial study were shown to increase over the course of the EFP, with an overall average of 1.75 swordfish/std. 8-h day. Additionally, the early EFP efforts reported a higher price-point received for deep-set landed swordfish compared to other concurrent domestic and foreign sourced product (i.e., drift gillnet, longline; Sepulveda and Aalbers, 2018; PFMC, 2020). Findings from the first 2 yr of EFP fishing effort were reported to NOAA (PFMC[1]) and published in Sepulveda and Aalbers (2018).

In 2017, PIER submitted a subsequent EFP application to test the use of linked buoy gear (LBG), a modified configuration of DSBG that retains serviceability but also connects all buoys, weights, and baited gangions to a single mainline (Fig. 1a; Aalbers et al., 2021). Following approval of the LBG EFP in September 2018, three cooperative fishermen were permitted to use both DSBG and LBG interchangeably, given that both gear configurations: 1) showed similar catch composition during research trials, 2) targeted similar depths, 3) incorporated active tending and strike indication, and 4) allowed for a maximum of 30 baited hooks per set (Fig 1a). Because both DSBG and LBG were new gear types that cooperative fishermen had not used previously, an effort was made to offer the EFP team flexibility on the simultaneous use of DSBG and LBG, so long as no more than 10 pieces of either DSBG or LBG were de-

The authors are with the Pfleger Institute of Environmental Research (PIER), Oceanside, CA 92054 (corresponding author: Chugey Sepulveda (chugey@pier.org)).

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[1]National Oceanic and Atmospheric Administration. 2019. (Avail. at https://www.federalregister.gov/documents/2019/03/04/2019-03493/fisheries-off-west-coast-states-highly-migratory-fisheries-amendment-6-to-fishery-management-plan, and accessed 10 May 2022.

ABSTRACT—This work reports on exempted and research fishing trials using Deep-set Buoy Gear (DSBG) and Linked Buoy Gear (LBG), two commercial gear types designed to target swordfish, Xiphias gladius, *off the coast of southern California. This study covers the period from 2017 to 2021 and supplements previous published data on the development and initial exempted fishing permit (EFP) trials of deep-set techniques for swordfish within the Southern California Bight (SCB; 2015–16). In this work, five cooperative EFP participants deployed 12,015 pieces of DSBG on 1,225 sets during 299 individual trips (mean=4.1 d/trip). DSBG catch composition was found to be similar to previously published data obtained from the first 2 years of exempted effort, with swordfish comprising ~94% of the total catch from 2017 to 2021. DSBG non-marketable catch (bycatch) primarily consisted of blue sharks and made up ~1% of the DSBG catch. Collective DSBG catch rates ranged from 1.2 to 2.1 swordfish per standardized 8-h fishing day (mean =1.7 swordfish/std. 8-h day) over the course of this study. Commercial exempted testing of LBG resulted in similar swordfish catch composition (~92%) and average daily catch rates (1.5–1.7 swordfish/std. 8-h day), with fewer overall species caught. Research sets using LBG yielded similar catch composition to DSBG and included a wider range of species than the exempted trials. The findings from this work align with previous exempted and research efforts using both DSBG and LBG and continue to suggest high selectivity in the developing California deep-set fishery for swordfish.*

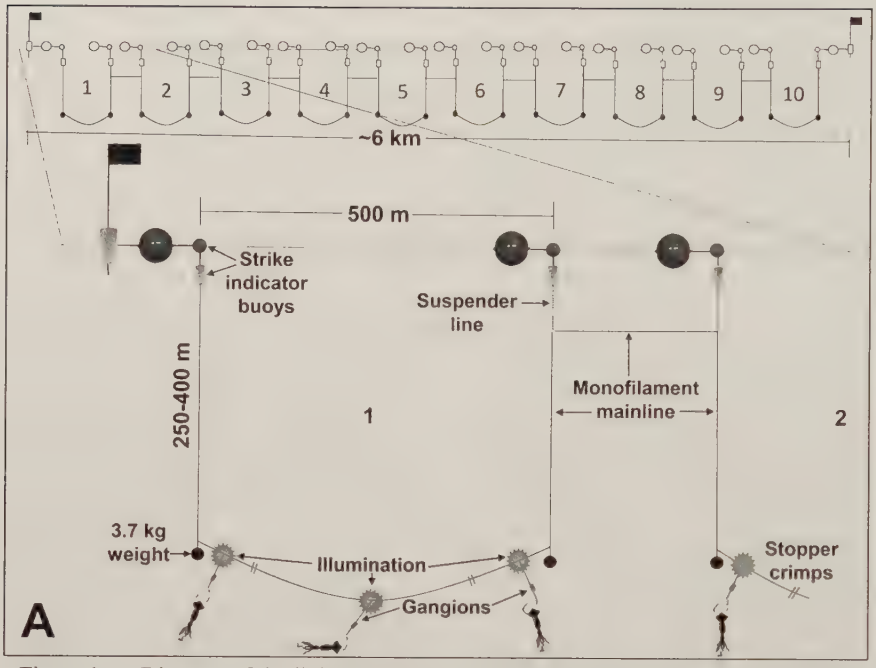

Figure 1a.—Diagram of the linked-buoy gear (LBG) configuration developed by PIER using up to 10 sections of monofilament mainline suspended from strike indicator buoys with heavy weights to descend baited hooks to depths exceeding 300 m.

ployed on a single day (i.e., 30-hook maximum).

During the DSBG and LBG exempted trials, concurrent research sets were performed from the PIER research vessel *Malolo* to further improve gear performance, train cooperative fishermen on its use, and conduct swordfish tagging and population dynamics research[2] (Sepulveda et al., 2019a; Griffiths et al., 2020). Collective catch and effort data from initial research and EFP trials were summarized to better inform NMFS and the PFMC prior to the preliminary authorization of DSBG and LBG in 2019 (Sepulveda and Aalbers, 2018).

This work reports on the results from exempted testing using both DSBG and LBG during the 2017–21 swordfish seasons as well as concurrent deep-set research trials performed from 2015 to 2022. The collective data sets are provided to further inform managers and stakeholders on catch rates, selectivity, and market trends for deep-set gear configurations targeting swordfish within the SCB.

Methods

Study Location and Permitting

Catch and effort statistics were summarized across five fishing seasons (2017–21) from up to six commercial vessels operating concurrently under a Highly Migratory Species (HMS) Exempted Fishing Permit (EFP) issued by NMFS. This work reports on two independent EFP's that were issued to PI Sepulveda and managed by PIER (PIER DSBG-EFP[3] and PIER LBG EFP[4]). The DSBG EFP included five vessels while the LBG EFP included four. Although the PIER DSBG-EFP was approved in 2015, this study reports on EFP activity since 2017, with findings from the initial two seasons of DSBG trials summarized by Sepulveda and Aalbers (2018).

All DSBG and LBG deployments, gear rigging, and set protocols followed the mandates outlined in the terms and conditions of the PIER DSBG and LBG EFP's and aligned with those described in Sepulveda and Aalbers (2018). EFP fishing was permitted to occur from the Oregon/Washington border (seaward off the coast at lat. 46.25°N) south to the Mexican border, excluding state waters off California (i.e., 3 nmi from the mainland and Channel Islands). All fishing occurred during daylight hours with gear haul-back initiated by sunset. Deep-set gear development and research trials were conducted under a NOAA Letter of Acknowledgment issued through the NMFS West Coast Regional Office (WCR) and a California Department of Fish and Wildlife (CDFW) Scientific Collection Permit (SCP-2471 and S-183330009-19106-001). PIER research trials were performed alongside cooperative fishermen operating under both DSBG and LBG EFP's, with catch being tagged and released (i.e., research catch was not sold and did not contribute to EFP landings).

Cooperative Fisherman Selection

Cooperative fishermen participating in the PIER EFP's were chosen based upon a selection rubric described in Sepulveda and Aalbers (2018). Briefly, parameters such as availability during the primary season (July–Dec.), previous swordfish experience, as well as willingness to cooperate and work as a unit were considered. Similarly, all cooperative fishermen needed to have valid permits, a violation-free history, and be willing to carry observers upon request. As described by Sepulveda and Aalbers (2018), the EFP manager (PI Sepulveda) was held equally liable and responsible for the actions of the EFP participants.

DSBG

The DSBG design and gear configuration used from 2017 to 2021 did not vary from that described during the first phase of the EFP trials (Sepulveda and

[2]National Oceanic and Atmospheric Administration (NOAA) Saltonstall-Kennedy Program (Grant # NA16NMF4270257; California Ocean Protection Council Grant # R/OPCSFAQ-07 issued through the Sea Grant College Program).

[3]Sepulveda, C. A. 2015. (Avail. at https://www.pcouncil.org/documents/2015/03/agenda-item-h-3-a-attachment-2.pdf/, and accessed 11 May 2022.

[4]Sepulveda, C. A. 2016. (Avail. at https://www.pcouncil.org/documents/2016/11/agenda-item-i-4-supplemental-attachment-1-pier-efp.pdf/, and accessed 11 Mar. 2022).

Aalbers, 2018). All EFP participants were provided identical gear sets that were designed and constructed by the EFP manager. Gear sets were measured to the nearest meter to ensure comparable rigging and performance. As described previously, all gear sets were designed to fish below the upper mixed layer with a set of crimps positioned at 90 m down the vertical mainline to demarcate the minimum hook depth.

Gear sets were designed to target depths between 250 and 350 m, with a maximum of 3 hooks per individual piece of gear and a maximum of 10 individual pieces deployed at one time (maximum of 30 hooks soaking simultaneously). Gangions were ~8 m long and constructed of 1.8–2.2 mm monofilament leader terminating with an 18/0 circle hook (Mustad model 39960DT)[5]. Battery-operated illumination (i.e., Power Light, SNL Corp., Fla.) was provided with fishermen given the choice of colors to be used (most deployments used either green or blue). Cooperative fishermen were also given the option to use either squid (*Illex* spp.) or finfish bait (i.e., chub mackerel, *Scomber japonicas;* saury or sanma, *Cololabis saira*). Although bait type was not logged for all EFP trips, *Illex* squid was predominantly used for bait on nearly all (>95%) DSBG sets.

Figure 1b.—Graphic depicting LBG suspended within the water column as designed to selectively target swordfish at depth during the daytime based on swordfish tagging data along southern California.

LBG

LBG design and construction was consistent across research and cooperative vessels, with all sets measured and built by the research team. As described previously by Aalbers et al. (2021), LBG sets consisted of up to 10 serviceable sections with fishermen given the option on how many sections they deploy daily (Fig. 1b). Each section used two 3.6 kg descending weights to expedite the sink rate of the monofilament mainline (2.8–3.2 mm) to a target depth between 250 and 400 m. Monofilament mainline was deployed from a hydraulic powered longline spool (super mini spool-28; Lindgren-Pittman, Pompano, Fla.) and all EFP sets included the use of a hydraulic line setter to further increase gear sink rates (LS-5, Lindgren-Pittman, Pompano, Fla.).

For each section, the vertical legs were suspended by a set of strike indicator buoys that were used on each end to signal when something was on the line, tethered to a ~15 m (≥50-ft suspender) monofilament suspender line (Fig. 1b; Sepulveda et al., 2019a; Aalbers et al., 2021). Upon visual detection of a strike, specific sections could be individually serviced using a hydraulic line puller (Pelagic Performance, San Diego, Calif.), and the section could be subsequently re-deployed with a fresh bait and reconnected to the mainline. Similar to DSBG, a maximum of 30 hooks per set (18/0 Mustad 39960D circle hooks) were baited with either squid or mackerel, with up to three gangions per section of LBG. In line with the DSBG deployments, gangions were ~8 m and outfitted with an illumination source and a 45 g swivel positioned ~2 m from the hook to expedite sink rate and reduce tangling upon retrieval.

Observation and EFP Monitoring

From 2017 to 2021, field observation of EFP activity was conducted through the NMFS WCR assigned contractor, Frank Orth and Associates (FOA, Long Beach, Calif.). EFP observer placement was managed by the WCR and FOA observer coordinator. Because DSBG demonstrated minimal bycatch and protected-species interactions during initial research (Sepulveda et al., 2014) and EFP trials (Sepulveda and Aalbers, 2018), NMFS maintained a lower observer coverage mandate on DSBG trips than for LBG. LBG trips required higher observation rates due

[5]Mention of trade names or commercial companies is for identification purposes only and does not imply endorsement by the National Marine Fisheries Service, NOAA

to the additional entanglement risk perceived by the NMFS Protected Resource Division (PRD). All EFP participants were required to notify PIER, NMFS, CDFW, and the FOA coordinator prior to each trip departure for determination of observer placement. Other considerations for carrying an observer included mandatory placement if drift gillnet gear was going to be fished on the same fishing trip.

In addition to physical monitors, vessels were also required to fill out logbook entries for every set made during the EFP and also comply with both a daily and trip level check-in and check-out procedure, as described by Sepulveda and Aalbers (2018). For all EFP activities, logbooks were collected monthly and analyzed by the PIER team independent of PFMC and WCR EFP assessments. All catch was collectively recorded using traditional CDFW landing receipts, logbook records, and daily fishing reports. Additionally, all swordfish landed by the PIER EFP group were tracked with traceability tags that were affixed near the collar of each fish. The traceability tags used a unique identification number, gear code, and vessel name that could be verified on the PIER website.

EFP Deployment Protocols

Cooperative fishermen were allowed the flexibility to deploy deep-set gear anywhere outside of California state waters (>3 nmi from the coastline or Channel Islands), as long as sets complied with the PIER-DSBG-EFP terms and conditions. Daily set location, duration, and amount of gear deployed was up to the discretion of the EFP participant, assuming that the combined total number of DSBG pieces and LBG sections did not exceed 10, and the total number of baited hooks did not exceed 30. In accordance with the EFP terms and conditions, DSBG and LBG sets had to be initiated after sunrise and gear haul-back procedures had to commence by sunset.

Catch and Bycatch Estimation

All catch was enumerated using logbook entries verified against CDFW landings receipts, daily check-in reports, and onboard observer records to ensure alignment of dates, catch statistics, and nontarget interaction rates. If discrepancies were identified, then individual fishermen were contacted directly to confirm and correct uncertainties. Swordfish size estimates, ex-vessel prices, and landing totals were derived from landing receipt and logbook records at the trip level. Mean market price and swordfish dressed weight values were calculated for each DSBG or LBG trip based on the ex-vessel revenues, total weight, and number of fish recorded on official landing receipts. Because the number of offloaded swordfish was not recorded on landing receipts prior to 2018, size and price estimates were only included if catch numbers at the trip level could be accurately validated from logbooks and daily check-in data. Mean ex-vessel values were weighted based on the percent volume of landed swordfish at each price point.

Specific size and price metrics from other marketable species, including bigeye thresher sharks, *Alopias superciliosus;* mako sharks, *Isurus oxyrinchus;* and escolar/oilfish, *Gempylidae*, were not estimated because of the low volume landed and inconsistent landing trends between species and vessels (some of which were retained for personal use).

Target and nontarget catch rates were standardized to 10 pieces of DSBG or 10 sections of LBG fished over an 8-h fishing day (std. 8-h day) to evaluate and compare catch and effort metrics with previous studies (Sepulveda et al, 2014; Sepulveda and Aalbers, 2018). Nontarget catch was further classified into either marketable or non-marketable species based on retention and if there was an existing market history for that species off the west coast.

Estimates for non-marketable catch, including marine mammals and species with extended federal or state protections, were calculated based on both actual and extrapolated values. Extrapolated catch estimates were performed for all non-marketable species based on the ratio of observer coverage to the total number of EFP set days. Because the only observed interaction with a northern elephant seal, *Mirounga angustristris,* resulted in a reported "live and alert" release, no further estimates of fishing mortality were performed.

Research Sets

DSBG and LBG research sets were performed aboard the PIER research vessel *Malolo* from 21 October 2015 through 06 January 2022. Because the primary objectives of the research trials were to further develop deep-set gear configurations and deploy electronic tags on live swordfish rather than maximize commercial harvest, research sets were analyzed and reported separately from EFP catch and effort data.

Considering that several deep-set gear configurations were tested over the course of research trials, only LBG sets that used the same configuration as EFP fishermen and targeted the same depths (250–400 m) were included in the analyses. As with previous experimental deployments, no catch was landed or retained for sale and all swordfish captured in good physical condition were outfitted with electronic tags for population dynamics and stock structure studies (Sepulveda et al., 2019a; Griffiths et al., 2020). Hook descent rates and fishing depths were determined from the archived records (30-s resolution; n=660) of depth and temperature sensitive data storage tags (DST's; Cefas Technology Ltd., Lowestoft, U.K.) affixed to gangion clips on each section of LBG sets deployed either with (n=17) or without (n=17) a line setter.

Data Analyses

Validated logbook records were categorized by vessel into a project database for subsequent analyses. Catch statistics were performed for all species that were retained for sale or intentionally released during gear trials and did not include species captured on other gear types (i.e., hook and line, harpoon). In line with previous analyses performed by Sepulveda

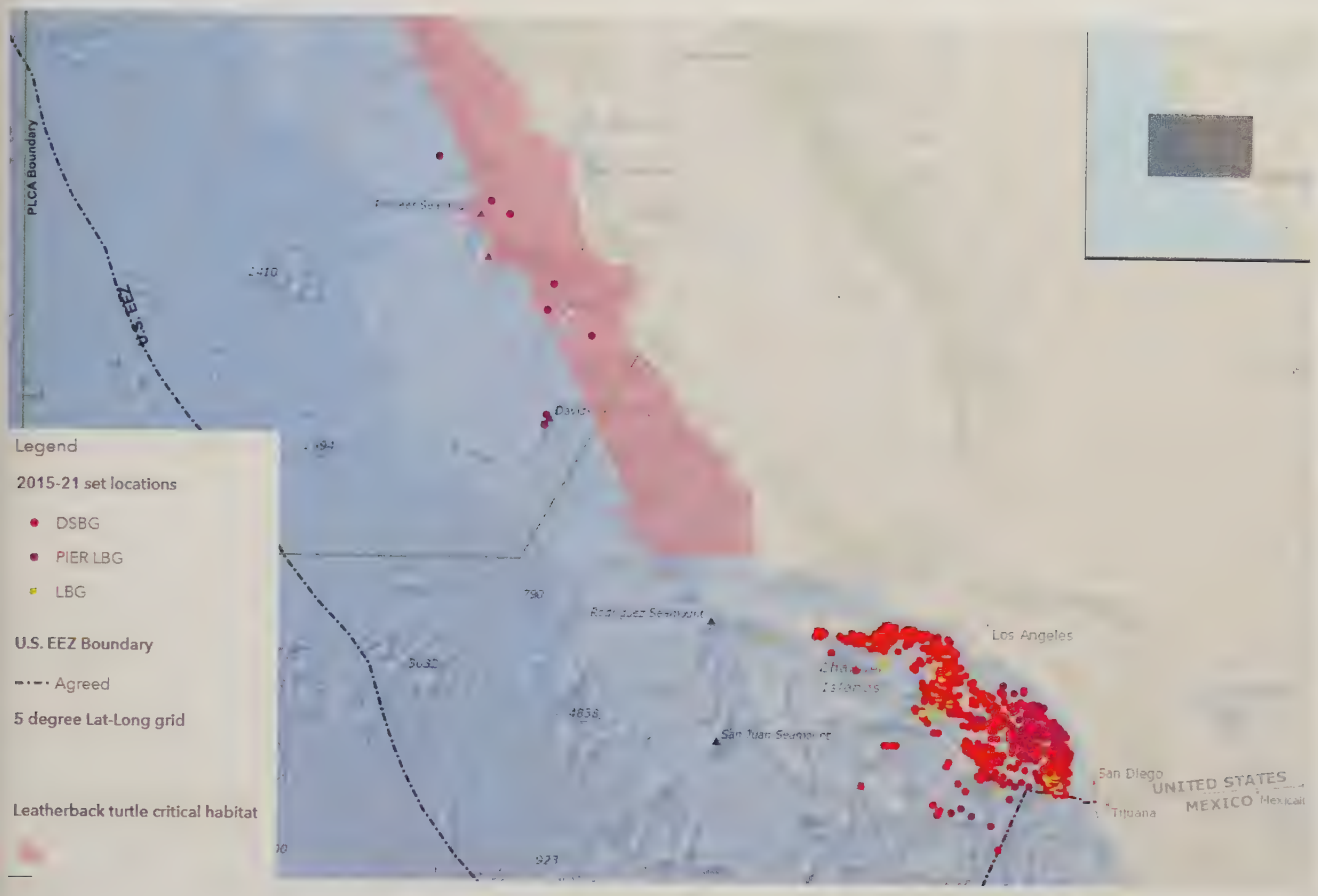

Figure 2.—Set locations of research and exempted fishing trials conducted off California from 2015–21 using both deep-set buoy gear and linked buoy gear.

and Aalbers (2018), data comparisons primarily focused on the number of set days, buoys/sections deployed, and soak duration.

Fishing effort was standardized to account for partial fishing days, that usually occurred on the first and last days of a trip because of travel or during periods of inclement weather. Effort standardization was based on typical EFP fishing conditions observed since 2015 and provided a consistent metric for comparison (Sepulveda and Aalbers, 2018). A standardized 8-h fishing day (std. 8-h day) was defined as ten pieces of buoy gear or ten sections of LBG soaked over an 8-h period.

Results

Location

All DSBG and LBG EFP sets occurred within the southern California Bight from Santa Cruz Island, Calif. (lat. 33.9°N, long. 119.8°W) to the Mexican border (lat. 32.6°N, long. 117.4°W; Fig. 2). Although set activity was permitted to occur within the entire 200 nmi exclusive economic zone (EEZ) off California, more than 90% of PIER EFP sets occurred from 3 to 30 nmi off the coast of southern California and around the Channel Islands. Research sets using DSBG and LBG were also primarily performed within the SCB; however, seasonal set activity extended up to the Farallon Islands off San Francisco, Calif.

DSBG Exempted Fishing Catch and Effort (2017–21)

Five EFP vessels deployed 12,015 pieces of DSBG on 1,225 sets during 299 individual trips (mean trip duration = 4.1 days) between 26 May 2017 and 03 December 2021. The total number of DSBG sets performed by the EFP group within a single season ranged from a high of 326 in 2017 to a low of 135 during 2021. Fishing effort fluctuated over the study period (Fig. 3a), with an overall average of 245 sets performed per season by the collective PIER EFP group. The maximum effort exhibited by any one vessel over the 5-yr study period was 396 DSBG sets performed.

Daily fishing times varied between vessels, with seasonal averages ranging from 6.8 to 7.4 h/set and a collective mean of 7.1 h/set. To allow for inter-annual comparisons between vessels, catch rates were normalized to an 8-h day, with a collective effort of 1,086 8-h day. Similarly, because nearly all sets consisted of 10 pieces of DSBG (mean = 9.9 pieces/set), fishing effort was standardized to a full 10 buoy compliment, which provid-

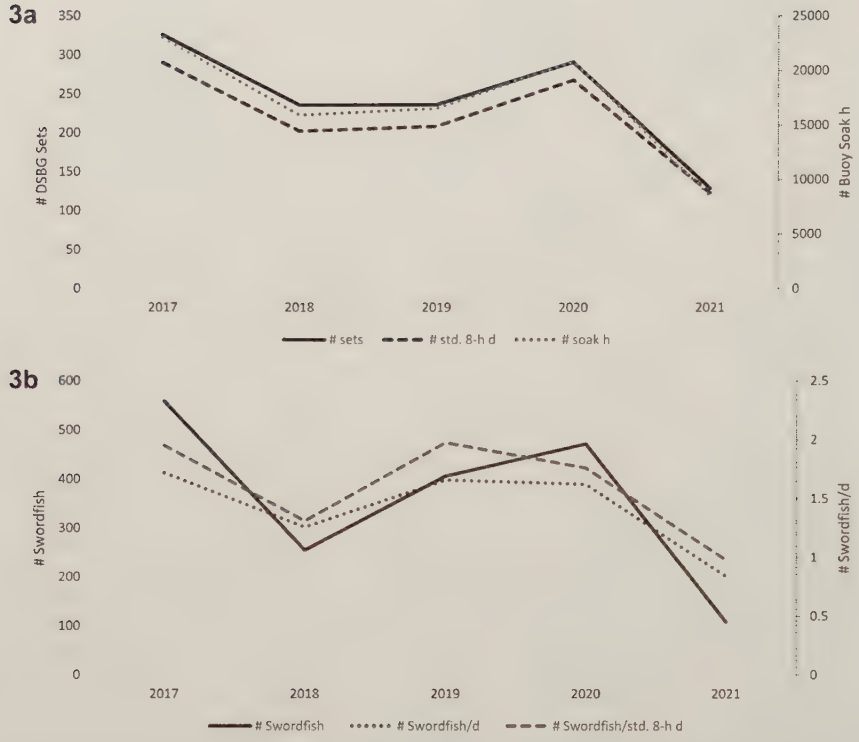

Figure 3.—Mean annual estimates of (a) fishing effort and (b) swordfish catch and CPUE during deep-set buoy gear exempted fishing trials conducted over five seasons (2017–21) off the coast of California.

ed a comprehensive effort estimate of 1,070 std. 8-h day over the EFP reporting period.

In total, 1,806 swordfish were caught on DSBG by five vessels from 2017 to 2021. Catch rates by vessel varied between seasons (Fig. 3b; Table 1), ranging from 1.1 to 1.7 swordfish per set (mean=1.4 swordfish/set), which equated to 1.2–2.1 swordfish per std. 8-h day (mean =1.7 swordfish/std. 8-h day). Annual catch rates, averaged across all EFP vessels, varied from a low of 0.8 swordfish per set in 2021 to a maximum of 1.7 swordfish per set in 2019 (mean=1.4 swordfish/set), with standardized annual catch rates ranging from 1.0 to 2.0 swordfish per std. 8-h day (mean=1.6 swordfish/std. 8-h day; Fig. 3b). The maximum seasonal catch rate observed for any EFP participant occurred during the 2019 season with 2.6 swordfish/set or 3.3 swordfish/std. 8-h day. The maximum daily catch rate observed in this study was 11 swordfish caught during a single set day using 10 pieces of DSBG.

Collectively, the mean catch rate was approximately 0.15 swordfish per individual piece of DSBG, or the equivalent of 1 swordfish for every ~6.7 DSBG pieces deployed. Although cooperative fishermen had the option to deploy up to three hooks per piece of DSBG, nearly all sets (<95%) consisted of a single 8 m gangion positioned at the terminal end of each vertical mainline rigged with a 18/0 circle hook baited with *Illex* squid.

Swordfish comprised 93.9% of the collective DSBG catch among EFP vessels, with bigeye thresher sharks (n=89) making up an additional 4.6% (Fig. 4, Table 2). Other marketable species, including escolar (n=7) and mako shark (n=3), comprised an additional 0.5% of the total catch. Species that were not retained for sale (i.e., non-marketable/bycatch) were typically released alive upon haul back and constituted the remaining 1.0% of DSBG catch, which included blue shark, *Prionace glauca* (n=16); salmon shark, *Lamna ditropis* (n=1); ocean sunfish, *Mola mola* (n=1); and a northern elephant seal, *Mirounga angustirostris* (n=1). The single protected species interaction was detected by the tending vessel with the strike indication system. The onboard observer reported that the male northern elephant seal was released in good physical condition within 20 min of the strike. Upon retrieval of the mainline, the release was accomplished by severing the monofilament leader < 3 m from the hook.

Collectively, 349 set days were monitored by NMFS-certified observers (29%), with coverage rates consistently maintained above 20% for all DSBG sets. Onboard observer records were consistently in agreement with logbooks (Table 3). An extrapolated interaction rate of 3.5 northern elephant seals was calculated based on the 29% observation coverage to align with Endangered Species Act (ESA) consultation process. Similar extrapolation estimates for all other non-marketable species interactions remained below 3% of the collective catch.

LBG Exempted Fishing Trials

Following issuance of the LBG EFP in September 2018, 475 LBG sections consisting of 1,425 hooks were deployed over the course of 52 sets by four EFP vessels during a 3-yr period. Daily fishing time averaged 7.3 h/set across vessels and seasons with a maximum daily soak duration of 10.8 h/set in 2020. A total of 380 fishing hours were accumulated across LBG EFP efforts. Similar to DSBG sets, LBG effort was normalized to an 8-h day (n=47.5 8-h day) and standardized to a full deployment of 10 full LBG sections (n=44.5 std. 8-h day).

A total of 69 swordfish made up 92.0% of the LBG catch, with marketable catch also including escolar (n=3), two bigeye thresher sharks, and a single mako shark. Across vessels, mean annual LBG catch rates ranged from a high of 2.1 swordfish per set in 2020 to a low of 0.9 swordfish per

Table 1.—Catch statistics among five commercial vessels during exempted fishing permit (EFP) trials using deep-set buoy gear to target swordfish (SF) off southern California from 2017–21, with some values standardized to an 8-h fishing day using 10 sets of gear (std. 8-h day).

EFP Vessel	# trips	# sets	Mean # day/trip	# buoys	# soak h	# 8-h day	# std 8-h day	# soak h/day	# SF/set	# SF/std 8-h day	# SF caught
FV *Gold Coast*	81	396	4.9	3,923	2,870	359	355.3	7.3	1.7	1.9	669
FV *Leah Gail*	85	342	4.0	3,380	2,336	292	288.6	6.8	1.7	2.1	596
FV *Three Boys*	55	167	3.0	1,598	1,314	164	157.0	7.9	1.2	1.2	193
FV *Aurelia*	60	228	3.8	2,280	1,522	190	190.2	6.7	1.1	1.3	251
FV *Spirit*	18	92	5.1	894	646	81	78.5	7.0	1.1	1.2	97
Total	299	1,225	4.1	12,075	8,688	1,086	1,069.6	7.1	1.5	1.7	1,806
Mean	59.8	245	4.2	2,415	1,737	217	214	7.1	1.4	1.6	361

set in 2018, which was equivalent to an average annual catch rate of 1.5–1.7 swordfish per std. 8-h day. Similar to DSBG, swordfish catch rates varied between vessels (Table 1), ranging from 0.6 to 1.6 swordfish per set, or 1.1–2.1 swordfish per std. 8-h day, with an overall mean catch rate of 1.5 swordfish per std. 8-h day. Collective catch rate averaged approximately 0.15 swordfish per section of LBG, with no observed non-marketable catch.

Due to mandates outlined in the EFP terms and conditions, observer coverage rates were maintained at 100% in 2018, but dropped to zero coverage during the 2020 fishing season due to staffing issues related to the Covid-19 pandemic. The overall observer coverage rate for the LBG EFP was 69%. Because all LBG catch was marketable and no protected species interactions were reported during the EFP trials, data extrapolations based on observer coverage were not calculated for LBG sets.

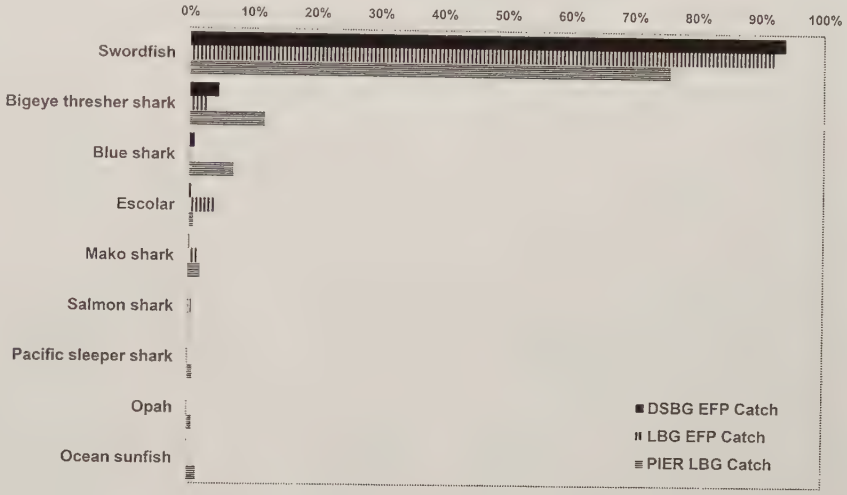

Figure 4.—Catch composition data from five cooperative fishing vessels collected from the deployment of 12,015 pieces of deep-set buoy gear (DSBG) on 1,225 sets during the PIER DSBG EFP trials between 26 May 2017 and 3 December 2021.

PIER LBG Research Sets

A total of 144 LBG research sets were performed aboard the PIER research vessel between San Francisco, Calif. (lat. 37.7°N, long. 123.0°W) and the Mexican border. The majority of PIER research sets (n=136) occurred within the SCB between October 2015 and January 2022, with eight LBG sets conducted above Point Conception, Calif. Experimental LBG sets were deployed either as a full complement of 10 sections (n=79) or in combination with DSBG (n=65; mean=6.2 sections/set), with an overall mean of 8.3 LBG sections per set. The initial 30 LBG sets performed in 2015 and early 2016 were deployed directly from the mainline spool, without the use of a hydraulic line setter. All sets performed after 12 October 2016 were performed using a hydraulic line setter to expedite gear deployment and hook sink rates. The line setter enabled two crew members to deploy LBG at a faster rate, with a full complement of 10 LBG sections set in approximately 60 ± 3.3 min, or ~6 min per LBG section.

A comparison of sink rates between LBG sets with and without a line setter showed that baited hooks remained in the upper mixed layer (<50 m) for a reduced amount of time (~3 min) when a setter was incorporated into the deployment. Sink rates increased from 10.0 m/min (without a setter) to 17.1 m/min when a setter was used. Additionally, without a line setter, the descent rate slowed considerably as depth increased, with baited hooks reaching target fishing depths (>250 m) more than three times faster when a line setter was used (median descent time=19.9 min) than during sets made directly from the spool (median descent time = 66.5 min). The mean settled fishing depth of hooks 1 and 3 of each section was approximately 295 m, while the middle hooks fished at an average maximum depth of ~370 m (Fig. 5).

Over the course of the research trials, average daily fishing time was approximately 7.4 h/set, which resulted in 1,058 fishing hours performed during the reporting period. For consistency and comparison with EFP efforts, research sets were normalized to a collective effort of 132 8-h day and a standardized deployment of 10 LBG sections (n=112 std. 8-h day).

Table 2.—Catch composition from exempted fishing permit (EFP; 2017–21) and PIER research (2015–21) trials using both deep-set buoy gear (DSBG) and linked-buoy gear (LBG) configurations.

Catch	Species	DSBG EFP catch (2017–21)	DSBG EFP catch (%)	LBG EFP catch (2018–21)	LBG EFP catch (%)	PIER LBG catch (2015–22)	PIER LBG catch (%)
Swordfish	*Xiphius gladius*	1806	93.9%	69	92.0%	225	76.3%
Opah	*Lampris guttatus*	0	0%	0	0.0%	2	0.7%
Bigeye thresher	*Alopias superciliosus*	89	4.6%	2	2.7%	31	10.5%
Pacific sleeper	*Somniosus pacificus*	0	0%	0	0.0%	2	0.7%
Mako shark	*Isurus oxyrinchus*	3	0.2%	1	1.3%	3	1.0%
Escolar/oilfish	*Gempylidae* spp.	7	0.4%	3	4.0%	2	0.7%
Salmon shark	*Lamna ditropis*	1	0.1%	0	0.0%	0	0.0%
Blue shark	*Prionace glauca*	16	0.8%	0	0.0%	26	8.8%
Common mola	*Mola mola*	0	0.0%	0	0.0%	4	1.4%
Pacific hake	*Merluccius productus*	0	0.0%	0	0.0%	2	0.7%
Protected species							
Elephant seal[1]	*Mirounga angustirostris*	1	0.1%	0	0.0%	0	0.0%

[1]Released Alive and Alert

A total of 225 swordfish were caught during LBG research trials, which comprised 76.3% of the collective catch. Other species captured on LBG included bigeye thresher sharks (n=31), blue sharks (n=26), ocean sunfish (n=4), mako sharks (n=3), escolar (n=2), opah, *Lampris incognitus* (n=2); Pacific sleeper sharks, *Somniosus pacificus* (n=2); and Pacific hake, *Merluccius productus* (n=2). Marketable species comprised approximately 90% of the total catch. Annual swordfish catch rates ranged from 1.1 swordfish per set in 2020 to 2.0 swordfish per set in 2017, or the equivalent of 1.3 to 2.7 swordfish per std. 8-h day. For all LBG research sets combined, the mean swordfish catch rate was approximately 1.5 swordfish per set or 2.0 swordfish per std. 8-h day. Catch rate across all research sets averaged approximately 0.19 swordfish per section of LBG.

Table 3.—Catch statistics recorded during exempted fishing permit (EFP) trials of deep-set buoy gear (DSBG) off southern California documenting agreement between most cooperative-fishermen logbook entries and NMFS-certified observer records.

Catch	Species	Recorded in logbook	Recorded by observer
Swordfish	*Xiphius gladius*	493	494
Bigeye thresher shark	*Alopias superciliosus*	42	42
Escolar/oilfish	*Gempylidae* spp.	2	4
Blue shark	*Prionace glauca*	5	5
Mako shark	*Isurus oxyrinchus*	2	2
Salmon shark	*Lamna ditropis*	1	1
Common thresher shark	*Alopias vulpinus*	0	1
Jumbo squid	Unidentified	1	1
Market squid	*Doryteuthis opalescens*	0	1
Pacific hake	*Merluccius productus*	0	2
Elephant seal	*Mirounga angustirostris*	1	1

EFP Effort and Landings

Based on a review of landing receipts and associated logbook records from all EFP vessels, swordfish caught on deep-set gear configurations ranged in size from 11 to 230 kg dressed with peduncle weight (DPW; Uchiyama et al., 1999), with an overall mean DPW of approximately 64.1 kg. Mean swordfish size based on landing receipt records increased slightly during each year of the study period from approximately 58 kg DPW in 2017 to approximately 71 kg DPW in 2021 (Table 4).

Based on the mean calculated swordfish size, collective EFP landings in California were estimated at 127 t from 2017 to 2021. Based on landing receipts verified against EFP logbook records, ex-vessel prices ranged from a low of $7.70/kg ($3.50/lb) during the winter of 2020 to a high of $25.30/kg ($11.50/lb) in the summer of 2021. The overall mean ex-vessel price received over the 5-yr study period was $13.90/kg ($6.30/lb), with a mode of $13.20/kg ($6.00/lb). However, the mean ex-vessel value increased nearly 25% in 2021 to approximately $18.25/kg ($8.30/lb), with a mode of $17.60/kg ($8.00/lb).

Monthly ex-vessel price across the study period went from a high of $18.00/kg ($8.20/lb) at the beginning of the season in July to a low mean price of $12.30/kg ($5.60/lb) in November. The seasonality of swordfish landings showed that catch occurred from June through January, with a peak number of swordfish landed during the month of October (Fig. 6). The majority of EFP fishing effort occurred from August through November and peaked in September, whereas research sets occurred across all months of the season (July–January).

Discussion

This study presents findings from the second phase of research and exempted testing of deep-set techniques targeting swordfish off southern California. The findings directly support previous exempted and research trials of DSBG and also provide comparable catch composition and gear trial data for LBG (Sepulveda et al., 2014; Sepulveda and Aalbers, 2018). This work also provides consistent inter-seasonal gear performance metrics (i.e., catch rates, composition, and selectivity) which continue to suggest that daytime deep setting can be used to target swordfish and simultaneously

avoid unmarketable bycatch off southern California (Sepulveda et al., 2014; Sepulveda and Aalbers, 2018).

Given the small regional footprint of the deep-set operations performed to date, the future growth and success of the fishery moving forward will depend on several factors including local swordfish availability, market dynamics, and resource competition between recreational and commercial fishing efforts. To promote growth and increase fishery resilience to changing ocean conditions as well as fluctuations in regional abundance, future deep-set fishery development efforts should focus on expanding to: 1) areas outside of the Southern California Bight, 2) seasons and configurations that result in the harvest of other valuable HMS, and 3) the development of markets to further reward fishermen for sustainably caught local seafood.

Given the continued decline of domestic swordfish operations off California and Hawaii (Urbisci et al., 2016; Helvey et al., 2017), competition with foreign-sourced product will continue to be the largest hurdle to face the future growth of any domestic west coast swordfish fishery. This problem further validates the need to expand deep-set gear catch portfolios and markets which may increase resilience in the developing domestic swordfish fleet.

Study Area

Throughout this study as well as in previous exempted trials, deep-set fishing has been largely confined to the SCB (Sepulveda and Aalbers, 2018), with most of the deployments performed off the southern California coastline and Channel Islands (Fig. 2). Limited spatial effort and the lack of expansion to other areas is likely due to several factors including the small size of most vessels participating in the EFP, the milder weather conditions within the Bight, and the increased costs associated with exploratory fishing.

Although several EFP fishermen expressed interest in targeting swordfish outside of the SCB, deep-set fishing largely occurred within day-trip

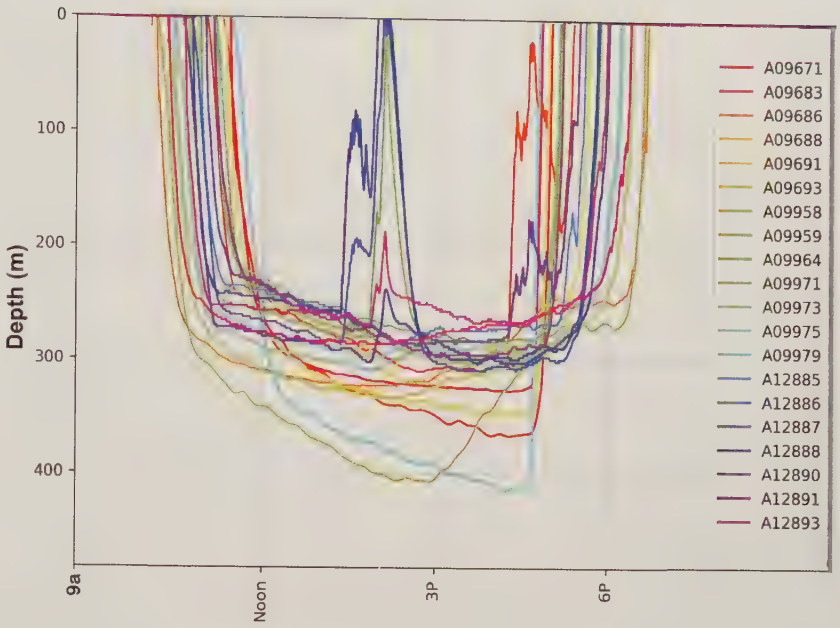

Figure 5.—Vertical profile of hook depths and descent rates from a linked-buoy gear (LBG) set on 26 January 2016 aboard the PIER research vessel, based on depth data obtained from 20 electronic tags affixed to baited gangions clipped along the horizontal mainline. Vertical spikes represent swordfish moving towards the surface following capture at depth and associated haulback events.

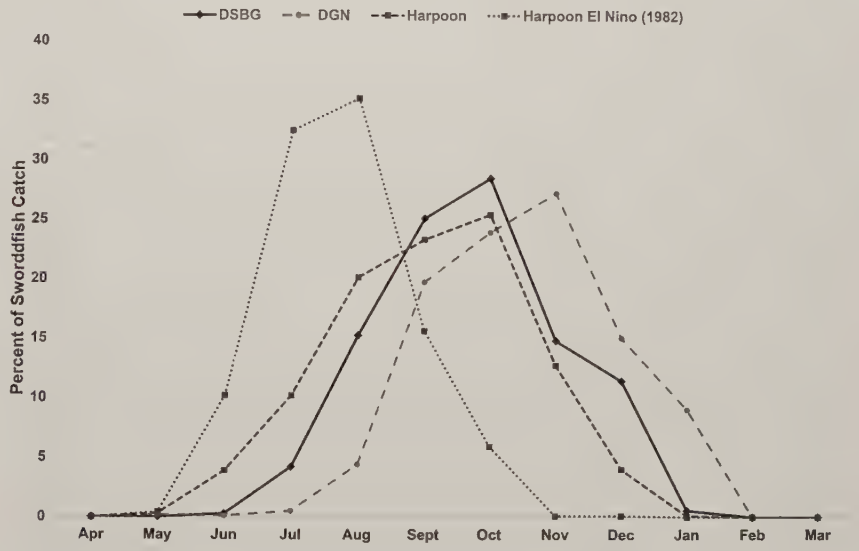

Figure 6.—Seasonal distribution of swordfish catch during exempted fishing trials using deep-set buoy gear (DSBG) from 2017–21 coupled with seasonal catch statistics for swordfish landed off California using both harpoon and drift-gillnet gear (1980–96), based on data from Coan et al. (1998) and Hanan et al. (1993).

range of secure and protected anchorages (i.e., harbor, island, or coastal embayment). The only sets made outside of the SCB were those performed by the research team during efforts to deploy electronic tags on swordfish within the Pacific Leatherback Conservation Area (PLCA) (Sepulveda et al., 2019a). The Sepulveda et al. (2019a) work provides insight into the use of deep-set gear off central and northern California and suggests that the techniques may prove to be productive outside of the SCB.

Due to the foul weather conditions commonly present above Point Conception and the higher variability in depth distribution of swordfish off Central California compared to the SCB, the research team consistently relied upon LBG over DSBG for the more northern deployments. This was mainly due the relative ease of monitoring LBG under all weather conditions as well as the expanded range of fishing depths covered by the gear (Sepulveda et al., 2019a). Given the added expenses associated with supporting longer duration trips and offshore fishing, it is likely that larger-vessel owners will feel the need to further expand current deep-set techniques (i.e., LBG) to ensure economic viability.

Although the EFP terms and conditions allowed participants flexibility on where to set, the observed temporal and spatial distribution of successful catches was similar between years, suggesting heightened resource availability within specific areas. Localized swordfish concentrations have been supported by Hanan et al. (1993) as well as recent tagging studies, which reported that swordfish tagged off California often return seasonally to specific locations year after year (Sepulveda et al., 2010; Sepulveda et al., 2019a; Griffiths et al., 2020; Sepulveda and Aalbers, 2022).

Similar site fidelity trends have been reported for swordfish around seamounts off Australia and in the Atlantic Ocean and have also been proposed in recent stable isotope analyses (Nielsen et al., 2009; Acosta-Pachón et al., 2020; Logan et al., 2021; Campbell and Hobday[6]; Wilcox[7]). Historic catch data off California as well as interviews with seasoned fishermen with over 40 years of experience also support the patchy distribution of swordfish off California and their seasonal occurrence within small pockets of regional productivity from year to year (Hanan et al., 1993; Sepulveda et al., 2010; Mintz[8]).

In this study, above average swordfish catch rates were typically aggregated in small areas of concentrated effort. For example, nearly 25% (n=125) of the swordfish landed on DSBG during the 2017 fishing season were caught by three of the participating EFP vessels fishing within a single 10 x10 nmi; CDFW statistical block in August–September 2017. Daily catch rates exceeded two swordfish per day during this period for the three vessels that fished within the aggregation area.

In contrast, the single vessel that avoided the crowded area and set in adjacent waters had a CPUE that was four times lower than the other vessels during the same period. The patchy distribution of the SCB swordfish resource will likely lead to future challenges between stakeholders, particularly as the deep-set commercial and recreational fisheries grow over time (Aalbers et al., 2022).

Swordfish Availability and Exempted Fishing Effort

Although swordfish availability off California is seasonal and dependent upon regional oceanic conditions (i.e., SST, productivity, currents), historic landings in the harpoon and drift gillnet (DGN) fisheries typically peak at different times, suggesting differences in seasonal gear vulnerability (Hanan et al., 1993; Coan et al., 1998; Sepulveda et al., 2010). The harpoon fishery typically starts in May, with a peak in July–August under El-Niño conditions or during October in other years and can extend through December (Coan et al., 1998; Fig. 6).

In contrast, the majority of swordfish landings from the California DGN fishery typically occur from August through January, with a peak in November (Fig. 6; Hanan et al., 1993). Although harpoon-caught swordfish were not included in this study, EFP fishermen recorded logbook entries for opportunistically harpooned swordfish from late May through December. Both DSBG and LBG catch and effort remained low through July and increased considerably in August, as reports of basking swordfish diminished (Krebs[9]). Over the course of the study, relatively consistent seasonal trends were observed between years, with the number of swordfish caught on DSBG peaking in October and slowly tapering off following the onset of driftnet fishing in November (Sepulveda and Aalbers., 2018; PFMC, 2020). In most years, DSBG catches remained high through December with effort diminishing into January as driftnet landings continued through the end of the month, a time when DGN activity typically shifted further offshore with the onset of winter conditions.

Although preliminary, initial findings suggest that deep-setting can complement the harpoon and drift-gillnet fisheries, as each of the three gear types have different peaks in performance that occur during different months of the year (Fig. 6). The variability in gear success is likely due to changes in seasonal movement patterns and depth distribution, which can influence gear effectiveness and swordfish catchability. For instance, surface basking behavior is often more prevalent in the early months (May–

[6]Campbell, R. A., and A. J. Hobday. 2003. Swordfish -seamount -environment -fishery interactions off eastern Australia. Working Paper presented to the 16th meeting of the Standing Committee on Tunas and Billfish, July 9–17, 2003 Mooloolaba, Australia. Hobart, Tasmania: CSIRO, Div. Mar. Res.

[7]Wilcox, C. 2014. Defining regional connections in southwestern Pacific broadbill swordfish. Fish. Res. Develop. Corp. Proj. 2007-036, Deakin, Victoria, Austr. (avail. at https://publications.csiro.au/rpr/download?pid=csiro:EP159228&dsid=DS2, accessed 11 June 2022).

[8]Mintz, S. Captain. Personal commun. F/V D.J., San Diego, Calif.

[9]Krebs, D., Captain. Personal commun. F/V Goldcoast, San Diego, Calif.

July) and sometimes completely absent in the winter (Sepulveda et al., 2010). Additionally, recent depth distribution data obtained from California swordfish suggests that the range of daytime depths broadens in the fall and early winter. The expanded daytime depth distribution in the later months (December–January) may support the use of gear types that cover a greater portion of the water column, like LBG, rather than more depth-specific gear types like DSBG (Sepulveda et al., 2019a). However, the exempted efforts performed during this study did not adequately test LBG during the late fall and early winter months.

During the exempted trials, deep-set fishing effort fluctuated from a high of 326 days fished in 2017 to a low of 135 days in 2021. The two primary factors that seemed to influence fishing effort the most were market price and catch rate. From 2018 through 2020, effort in the late fall (November–December) decreased substantially when market price fell below $5.00/lb for dressed swordfish. For this 3-yr period, the market price dipped below the $5/lb threshold when the volume of swordfish landed by the California driftnet fishery began to increase or when foreign import volume (i.e., Mexico, Ecuador) began to rise during the late fall and winter months (Heflin[10]).

Throughout the EFP period, it was apparent from deep-set research trials that swordfish remained locally available and accessible on deep-set gear well after EFP fishing effort ceased. When EFP fishermen were asked why they stopped fishing, all respondents noted that the price was too low to offset trip costs and that market variability became too high to support continued effort.

Throughout 2021, market price remained well above the $5.00/lb threshold, with an average price of approximately $8.00/lb across the entire season; however, fish availability and catch rates were lower than previous years. In 2021, the average catch rate of the EFP vessels dropped below one swordfish per day for the first time since the EFP started (Sepulveda and Aalbers, 2018). However, because both the price and the average swordfish size were both higher than any other year, deep-set fishing effort continued (although limited) through the end of the year for several of the EFP vessels. Limitations on fresh-seafood imports due to shipping and supply-chain constraints likely helped reduce import volume and supported higher swordfish prices throughout the 2021 season. Similarly reduced landings were also reported in 2021 from both the CA DGN and neighboring Mexican longline fishery, suggesting reduced local volume/availability (Sosa-Nishizaki[11]). The lack of DGN and Mexican landings also likely contributed to the stability of the deep-set swordfish market in 2021.

One factor that also influenced the productivity and landings generated from the PIER EFP's was the amount of effort individual fishermen dedicated toward targeting swordfish. Although this work only incorporated full-time fishermen in the EFP selection process, all of the vessel operators are portfolio fishermen who also engage in other fisheries and or work. Throughout the EFP period, there were several instances in which fishermen used deep-set gear for only brief periods of a season, with some sitting out an entire season.

As the fishery moves towards authorization, this type of intermittent and sporadic effort will likely be common, as portfolio fishermen who participate in seasonal fisheries often weigh their options on where to focus their effort on a daily basis. Increased effort and success was observed by those cooperative EFP participants that maintained communication with each other, a strategy that have enabled the group to better track small pockets of productivity and increase CPUE.

Catch Composition

The catch composition reported in this study as well as that documented previously showed that there were relatively few species caught and that swordfish and bigeye thresher sharks (BETS) consistently made up the bulk of the catch (Fig. 4). Over the course of the entire EFP (2015–21), the team observed an increase in gear selectivity for swordfish that ranged from 64% in 2015 (Sepulveda and Aalbers, 2018) to 97% of the catch in 2021 (this study). Increased gear selectivity may be attributed to experience in avoiding areas of high BETS abundance, as BETS are often caught in association with specific bathymetric features, such as submarine canyons and seamounts (Aalbers et al., 2021). Although BETS are marketable, most fishermen in the PIER-EFP preferred to release this species due to their resiliency (i.e., being alive at haul back) and low-market value.

To better inform fishermen and management on post-release disposition, BETS caught during both research and EFP efforts were tagged to document survival rates following release on both DSBG (Sepulveda et al., 2019b) and LBG (Aalbers et al., 2021). Bigeye thresher sharks captured on both DSBG and LBG exhibited relatively high post-release survival rates (~93%), which further encouraged fishermen to release BETS in the latter years of the EFP.

Other marketable catch, like opah, were also more prevalent during the initial 2 years of EFP trials (2015–16) (Sepulveda and Aalbers, 2018), which may be partially attributed to changes in fisherman behavior. In the early years of the EFP, fishermen often used up to three vertically-spaced hooks on each piece of DSBG, while nearly all sets after 2016 consisted of just one terminal hook at the bottom of the gear. The transition to using a single baited hook occurred due to frequent tangles on upper gangions and the low financial return from the additional bait investment. Removing the upper hooks from DSBG sets

[10]Heflin, J. Chula Seafoods, San Diego, Calif. Personal commun.

[11]Sosa-Nishizaki, O. CICESE Professor, Ensenada Mex., Personal commun.

may have resulted in fewer mid-water or thermocline-associated species (i.e., opah, mako sharks, common thresher sharks, *Alopias vulpinus*), as reported by Sepulveda et al. (2018).

Non-marketable catch (bycatch) primarily consisted of blue sharks, a common species that is largely discarded in most domestic HMS fisheries in the North Pacific (Hanan et al. 1993; Campana et al., 2009). Although post-release disposition for blue sharks caught on deep-set gear has not yet been studied, it does not appear that projected catches from a larger fleet would be a major conservation concern based on the low blue shark catch rates observed in deep-set EFP efforts to date[12] (Sepulveda et al., 2018).

For example, the total number of blue sharks caught in both previously reported EFP efforts (n=8; Sepulveda and Aalbers, 2018) and in this study (n=23) collectively represent less than the average number caught in one single shallow-set longline deployment in the North Pacific (Moyes et al., 2006; Campana et al., 2009). However, because most of the blue shark catches observed during research trials occurred during sets made outside the SCB or later in the season (November–February), it may be that future efforts from an expanded California fleet would result in slightly higher blue shark catches compared to findings presented here.

Observation and Catch Reporting

Considering that this EFP incorporated several additional accountability measures (i.e., physical observers, daily check-ins, electronic monitoring), it was not surprising that self-reported logbooks showed high agreement with NMFS-trained observer data records (Table 3). Given that logbooks did not vary significantly from physical observer records and because of the very low numbers of non-retained catch, catch estimates were not extrapolated for all incidental catch. To account for any under-reporting of the most prevalent bycatch species observed in this study, an extrapolation of the blue shark catch (n=23) would still only amount to 81 individuals caught and released by all fishermen over the entire study period.

Deep-set Configurations

Although DSBG and LBG vary in configuration and deployment methods, similar bycatch mitigation features were incorporated into both deep-set gear designs (Aalbers et al., 2021). Both DSBG and LBG were designed to descend rapidly through the upper-mixed layer to similar target depths and each possess strike detection capacity which allows for rapid processing of catch (Fig. 1). The primary advantages of LBG are that all baited hooks can be deployed at target swordfish depths along the deep horizontal sections of mainline (depths of 250–400 m) and that the interconnected configuration of the gear can make it easier to monitor and keep track of compared to individual pieces of DSBG.

In contrast, DSBG has the advantage of being more precise and maneuverable, and it is easier to deploy and retrieve. Additionally, DSBG is very simple, requires fewer crew, and has a set-up cost that is roughly half that of LBG. The deployment and haul back of LBG is more technical and time consuming and requires the use of additional equipment (i.e., hydraulic line setter, longline spool). Several fishermen expressed concern over the need to have either competent or additional crew for the deployment of LBG, while less-experienced crew members were capable of DSBG deployments (Krebs[9]).

Although PIER has seamlessly deployed LBG research sets since 2015 and worked directly with cooperative fishermen on LBG set-up, training, and setting, the EFP team continued to rely more heavily on DSBG. In addition to the technical challenges associated with LBG deployments, several factors may have further contributed to reduced LBG effort.

One major difference between the DSBG and LBG EFP's was that the terms and conditions of the EFP mandated 100% observer coverage for LBG, compared to a 20%–30% observation mandate for DSBG. The 100% observer coverage rate reduced LBG effort as fishermen could not deploy LBG unless a NMFS-certified observer was assigned to the vessel prior to departure, which was often weighed by fishermen, particularly during periods when COVID-19 exposure was a concern (2020–21).

Additionally, the increased complexity of LBG deployment and haul-back procedures required more-experienced crew members, which were often difficult to acquire, especially in the latter years of the EFP when unemployment rates were at near record lows[13]. The increased costs associated with the deployment of LBG also likely influenced the collective number of sets performed, as fishermen ideally needed one extra crew member and also had to purchase additional baits for each LBG set (30 vs. 10). It was also the case that LBG sets were reduced among fishermen that predominantly fished close to the coastline or around offshore banks and pinnacles because LBG hangs across a greater depth range and is less maneuverable than DSBG.

Concern was also expressed over setting LBG close to other DSBG fishermen, so EFP fishermen were more inclined to use DSBG if there were other vessels present. Because DSBG consists of a single mainline suspended vertically from a series of surface floats, DSBG is more versatile than LBG and can be deployed in almost any situation regardless of bathymetric features (>300 m) or proximity to other sets of gear. It is likely that future trends in gear use will continue to favor DSBG configurations within the SCB, while LBG will be more commonly used by larger vessels fishing in offshore waters.

[12]U.S. Dep. Commer. NOAA. 2021 (avail. at https://media.fisheries.noaa.gov/2021-08/Draft-EIS_Authorization-DeepSetBuoyGear.pdf), and accessed 11 May 2022.

[13]U.S. Dep. Labor. 2022. Bureau of Labor Statistics, Regional and state unemployment-2021 annual averages. Avail. at https://www.bls.gov/news.release/pdf/srgune.pdf, and accessed 4 June 2022.

LBG EFP Catch

LBG yielded similar catch composition as DSBG over the course of the study, with swordfish making up > 92% of the total catch across both EFP's (Sepulveda and Aalbers, 2018). Although several EFP vessels have demonstrated success using LBG, the slightly higher LBG swordfish catch rates were apparently not sufficient to warrant the additional logistical and financial burden associated with LBG deployments. Thus, direct comparison of catch rates between DSBG and LBG are premature and may be misleading given the differences in sample sizes and because sets were conducted on different spatial or temporal scales. The limited number of LBG deployments by any single EFP vessel and the lack of full-season comparisons between fishermen also prevented valid assessments between the two gear types.

Subtle differences in the catch rates of target and nontarget species using DSBG and LBG were likely related to the timing and location of sets. For example, the blue shark catch was shown to be higher during both the DSBG EFP and the PIER LBG research trials when compared to the LBG EFP trials. This is most likely due to the seasonality of sets, as the research sets during the same period revealed similar catch composition. Further, nearly all LBG EFP sets occurred during the months of July through October, whereas the majority of the blue shark catch occurred later in the swordfish season (November–January) when blue shark abundance increased off southern California (Hanan et al., 1993; Sepulveda and Aalbers, 2018; Godínez-Padilla et al., 2022).

PIER LBG Research Trials

Throughout the EFP period, LBG research sets were conducted by PIER to further develop and increase gear performance and simultaneously perform tagging studies to address questions related to swordfish habitat utilization and stock structure. In contrast to the EFP trials, which focused exclusively on maximizing target catch, the research team took measures to optimize tagging success and post-release survival, usually at the expense of maximized production. Additionally, in some instances, directed sets were made to target species other than swordfish, such as directed sets for BETS to assess post release survival (Aalbers et al., 2021).

Because measures such as reducing the amount of gear set on a given day and setting to target species other than swordfish were sometimes employed, LBG research sets do not provide an accurate assessment of true catch potential. For instance, on 8 December 2018, the team tagged 8 swordfish on 5 sections of LBG and refrained from setting additional gear to avoid having too many fish on the line at the same time. The research vessel then returned to port, rather than making additional sets in the area to capitalize on the swordfish aggregation. Similarly, the slightly higher BETS catch rate observed during the research sets is likely an artifact of set location and intentional targeting for tagging purposes (i.e., setting in locations that previously resulted in BETS catch).

Additionally, to assess seasonal trends in catch and gear performance, research sets were conducted across the entire study period and throughout the entire swordfish season (July–January). This resulted in much shorter trips than the commercial vessels participating in the PIER EFP's and spread effort out more evenly across the season. Although data from research sets may underestimate the true catch potential of LBG, a comparison of catch rates from EFP and research trials showed that they were similar, and in several years the research catch rates were higher than those of the EFP participants. Additionally, the research sets were also used as a training platform to demonstrate LBG deployment and haul-back procedures and provide cooperative fishermen training on the use of LBG.

Collectively, LBG research catch consisted predominantly of swordfish (76.3%), bigeye thresher sharks (10.5%), and blue sharks (8.8%), and catch composition included a wider variety of species than LBG EFP sets. Small numbers of other marketable species (i.e., opah, mako sharks, escolar, Pacific hake) contributed to an additional 2.4% of the catch and nonmarketable species (i.e., ocean sunfish, Pacific sleeper sharks) comprised another 2.0% of the catch.

Differences in catch composition and rate between research and EFP vessels were likely due to set location, time of year, and subtle gear changes that occurred over the course of developing LBG. For instance, many of the blue sharks caught during the LBG research sets occurred either late in the fishing season (November–February), outside of the SCB fishing grounds in areas that were not fished by EFP vessels, or prior to the use of a hydraulic line setter (a tool that expedited hook sink rates, incorporated in October 2016). Hydraulic line setters strip mainline from the primary spool at an adjustable rate to increase the amount of slack in the line as it enters the water, which allows the gear to sink at a faster rate.

Line setters have been shown to reduce interaction rates with nontarget, surface-oriented species in tuna fisheries while simultaneously increasing target catch on deep-set longlines (Beverly and Robinson, 2004; Beverly et al.[14]). In this study, we observed much faster hook-decent rates when using a line setter, with baited hooks remaining within the upper-mixed layer for less than ~3 min. Because most bycatch interactions occur above the thermocline (reviewed by Swimmer et al., 2020), higher sink rates likely contribute to the selectivity observed in this study.

Despite conducting LBG research sets across multiple areas over a 7-yr period, no interactions with threatened or protected species listed under ESA or the Marine Mammal Protection Act were recorded, suggesting that fu-

[14]Beverly, S., L. Chapman, and W. Sokimi. 2003. Horizontal longline fishing methods and techniques: a manual for fishermen. Secretariat Pac. Community, New Caledonia, 130 p.

ture fishery interaction rates with sensitive species have the potential to remain low. Additionally, LBG research sets conducted within portions of the PLCA off central California were successful in catching swordfish while avoiding protected species, despite numerous observations of marine mammals (i.e., sperm whales, *Physeter microcephalus*; fin whales, *Balaenoptera physalus*; elephant seals, and orcas, *Orcinus orca*) around gear sets (Sepulveda et al., 2019a). Although additional research and EFP sets within the PLCA are necessary to better assess LBG performance (i.e., maintaining catch while avoiding protected species), initial trials have suggested that deep-set techniques may provide a way for fishermen to sustainably capitalize on the swordfish resource that seasonally resides within the productive waters off northern California and Oregon.

EFP Revenues

Previous work by Sepulveda and Aalbers (2018) performed a cursory analysis of revenues and related expenses associated with swordfish catches. In this study, revenues from concurrent fishing activities outside of deep-setting (i.e., harpooning or hook-and-line fishing) were relatively minimal for both EFP's. However, fishermen often reported the use of harpoon methods for swordfish as well as trolling for other HMS (i.e., Pacific bluefin tuna, *Thunnus thynnus*) during a set. Additionally, deep-set fishermen reported harpooning swordfish that were lost during DSBG retrieval, as fatigued swordfish often surfaced after struggling on the line (Krebs[9]).

Revenues from other marketable species caught on either DSBG or LBG were also minimal, particularly after fishermen transitioned towards using a single baited hook early in the trials. Because most EFP fishermen primarily targeted swordfish by location, time of year, and hook depth, incidental catch rates were low, especially in the latter portion of the EFP when fishermen used past experience to guide set locations. As the deep-set fishery grows or during periods of reduced swordfish availability, future efforts will likely expand to include fishing at different times of the year and varying target depths, which will likely lead to additional revenues from other marketable catch species (e.g., opah, tuna).

Next Steps

In September 2019, the combination of gear performance and catch data from both PIER research and EFP activities was used to inform and advance the gear authorization of DSBG and LBG by the PFMC[15] under the Fishery Management Plan for U.S. West Coast Fisheries for Highly Migratory Species (HMS FMP). This work has also helped promote the use of low-impact fishing techniques and has strengthened local fishing opportunities for swordfish off southern California.

Although this work has made a step towards increasing sustainable domestic fishing opportunities, as of this publication most of the California swordfish grounds still remain unfished. The massive PLCA encompasses a productive region that once supported considerable fishing effort and swordfish harvest from the California DGN fishery (Hanan et al., 1993). The swordfish resource along central and northern California has been proposed to be part of the western and central North Pacific swordfish stock, a stock that is currently considered to be healthy (WCPFC, 2018; IATTC, 2021; Brodziak and Ishimura[16]). To grow the deep-set fishery and also help develop our domestic fleet, there is a need to expand efforts beyond the areas currently fished and also broaden the current catch portfolio to include other valuable HMS that can be sustainably harvested within California waters.

[15]PFMC. Deep-set Buoy Gear Authorization Final Action (avail. at https://www.pcouncil.org/documents/2019/09/agenda-item-i-4-situation-summary.pdf/, and accessed 23 June 2022).

[16]Brodziak, J., and G. Ishimura. 2010. Stock assessment of North Pacific swordfish (Xiphias gladius) in 2009. NMFS Pac. Isl. Fish. Sci. Cent., Admin. Rep. H-10-01, 37 p. (avail. at https://repository.library.noaa.gov/view/noaa/3749, and accessed 11 Jan. 2023).

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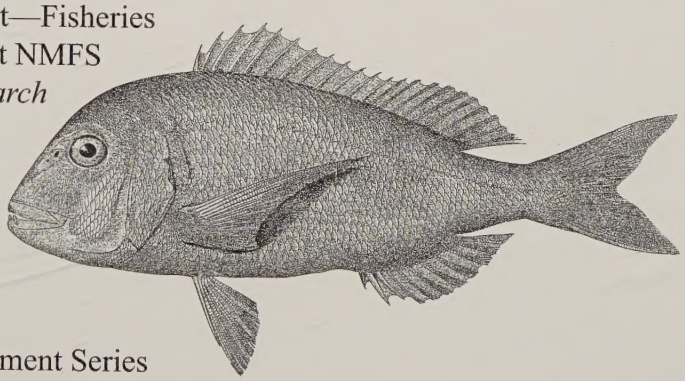

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